EDWARD MOYSE

EVENT DISPLAYS IN HEP

INTRODUCTION

- What do we mean by Event Displays?
  - Perhaps better to define what we use them **for…**
- Examples of use cases:
  - **Monitoring**
  - **Detector geometry debugging**
  - **Reconstruction / Simulation software debugging**
  - **Physics discovery / interpretation**
  - **Outreach**

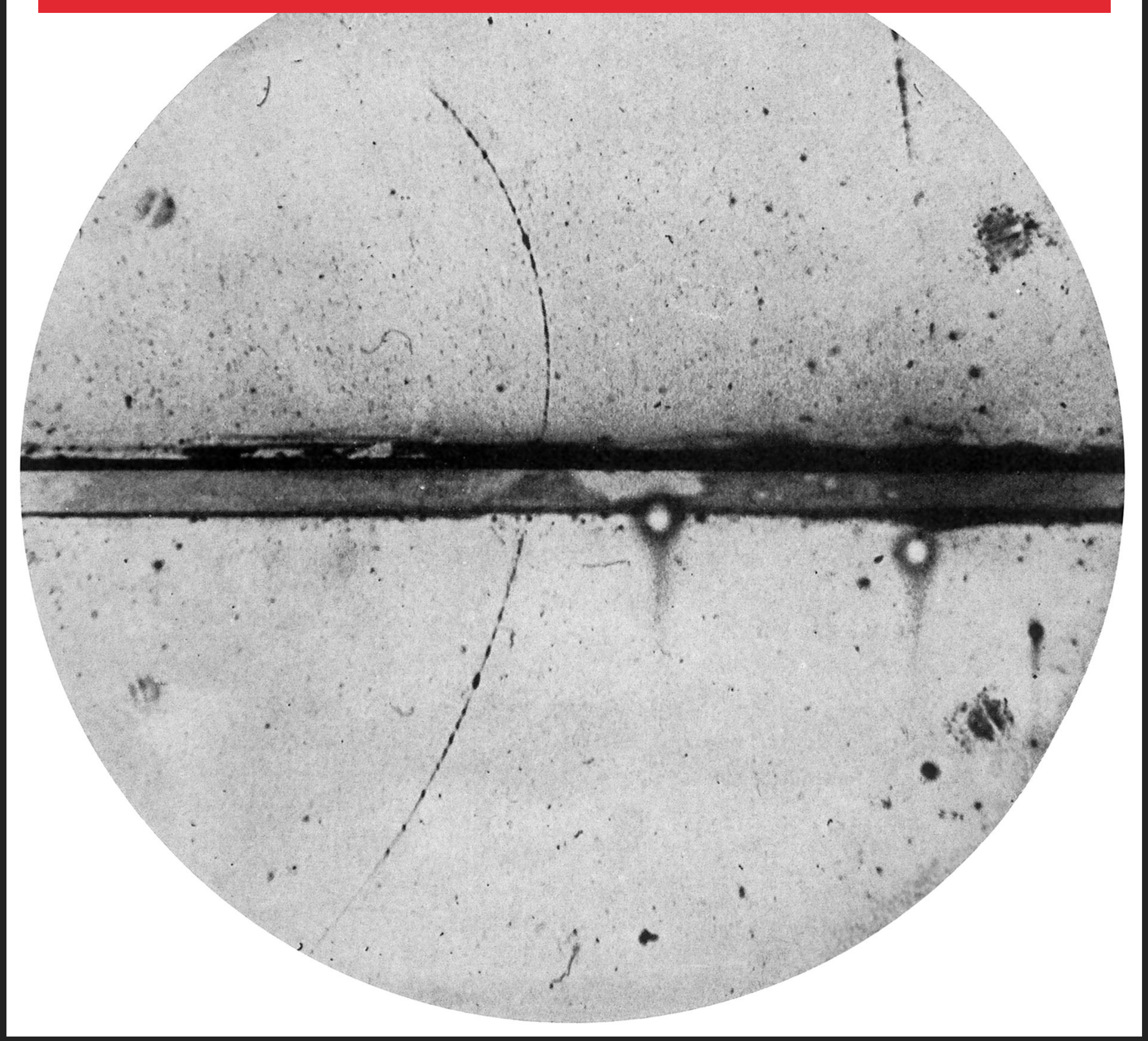
INTRODUCTION (2)

- I will try to cover as much of the above as I can in this presentation
    - Apologies that much of my talk will by focused on the ATLAS detector (it's just what I know best)
    - There will also be some bias towards the particular ATLAS event display(s) I helped write (for similar reasons)
    - Much of this talk is taken from previous material presented by *Riccardo Bianchi* and others, and from CERN websites (so thanks very much to all involved)
- **I will start with a little history…**

HISTORY

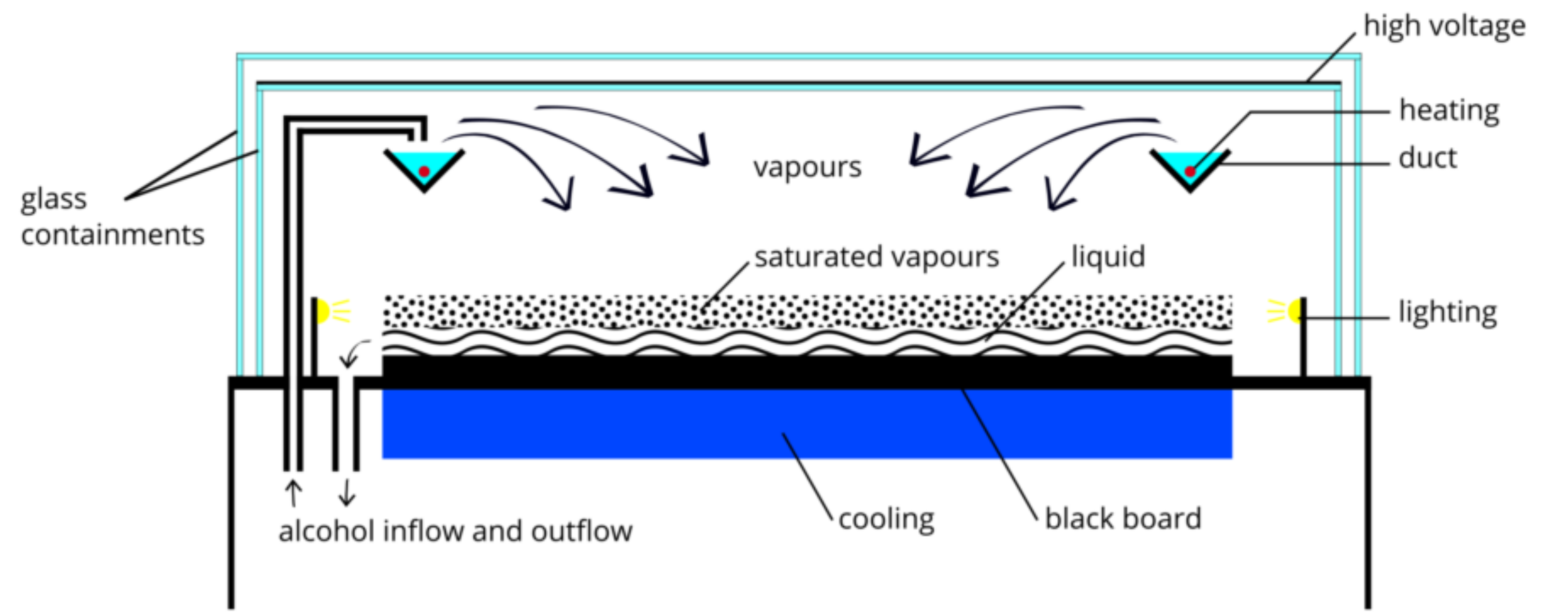
- Subatomic particles are too small to see with human eyes, so physicists have always relied on detectors to find them
  - For more, see this CERN article (which is the basis for most of the next few slides)
- Initially **data acquisition and event display were the same**, as we used photographs of **cloud chambers**:
  - First invented in 1911 by Charles Thomson Rees Wilson
  - He was awarded the Nobel prize in 1927 (together with Arthur Compton)
- Types include:
  - Expansion cloud chamber
  - Diffusion cloud chamber (see next slide)

1932: CLOUD CHAMBER PHOTOGRAPH OF THE FIRST POSITRON EVER DISCOVERED



DIFFUSION CLOUD CHAMBER

[wiki]

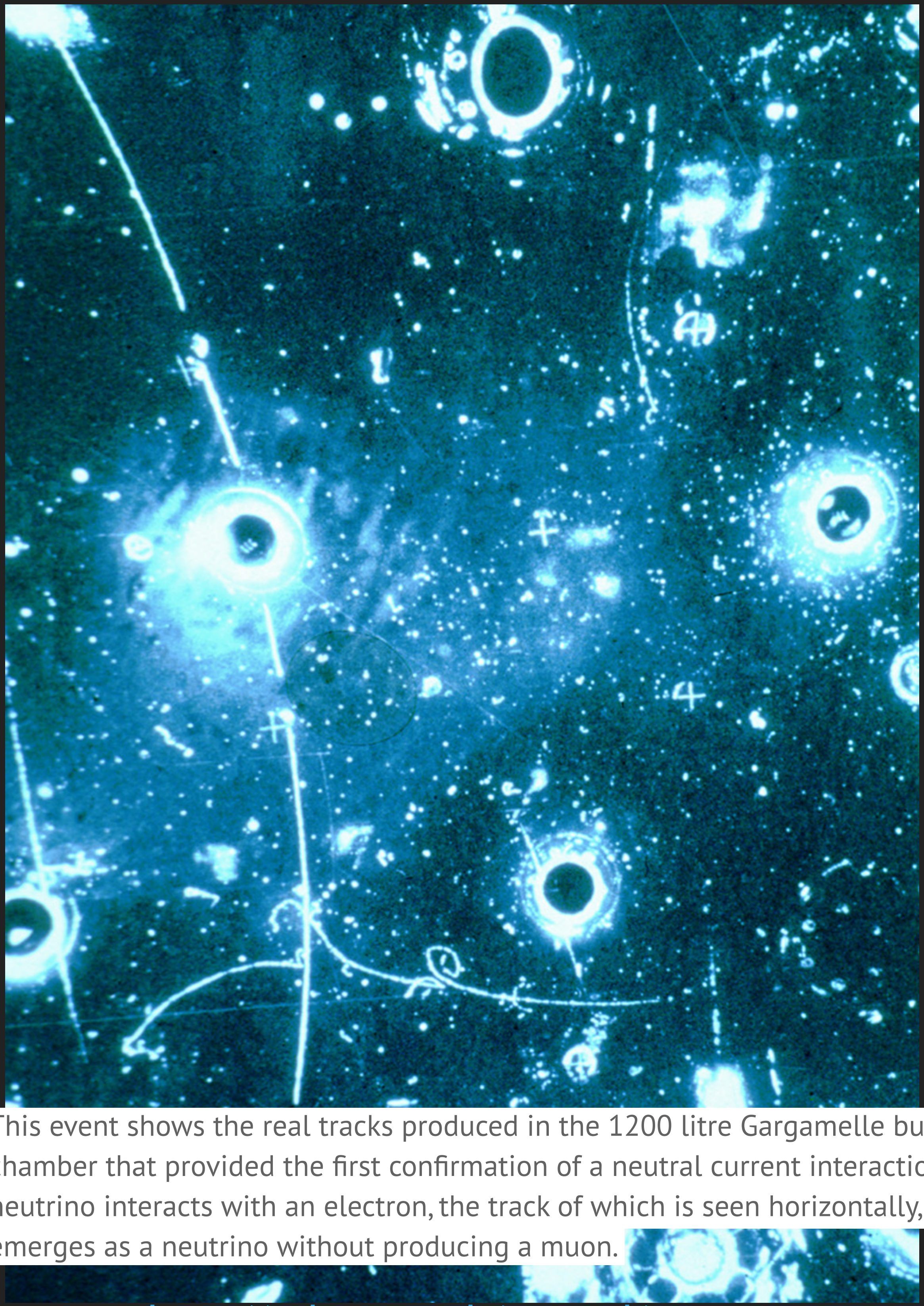


By Nuledo - https://www.nuledo.com/en/cloud-chambers/, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=62073628

- Alcohol vapour saturates the chamber, which has a steep temperature gradient
- Charged particles leave trails in the supersaturated vapour
- An electric field can be used to increase the size of the optimal detection region

BUBBLE CHAMBERS

- Replaced by bubble chambers
    - Invented by Donald A. Glaser in 1952
        - Awarded the Nobel prize in 1960
    - Work by a similar technique, but superheated liquid is used to create ionisation track instead of gas
    - CERN's 1000 ton Gargamelle was one example… and was instrumental in the 1973 discovery of weak neutral currents
        - (Electroweak theory won 1979 Nobel prize for Sheldon Glashow, Steven Weinberg, and Abdus Salam)

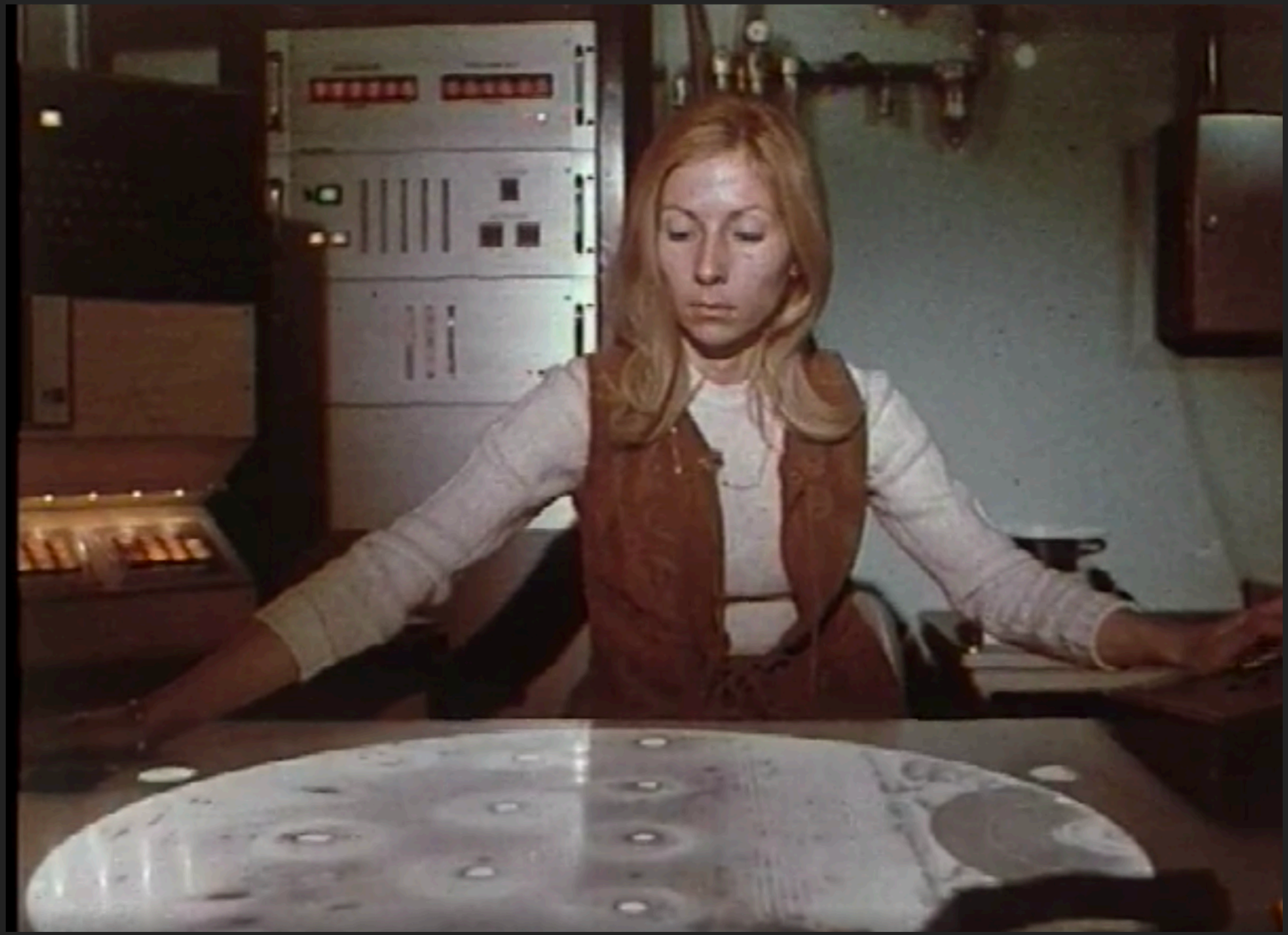


This event shows the real tracks produced in the 1200 litre Gargamelle bubble chamber that provided the first confirmation of a neutral current interaction. A neutrino interacts with an electron, the track of which is seen horizontally, and emerges as a neutrino without producing a muon.

http://cds.cern.ch/record/39468

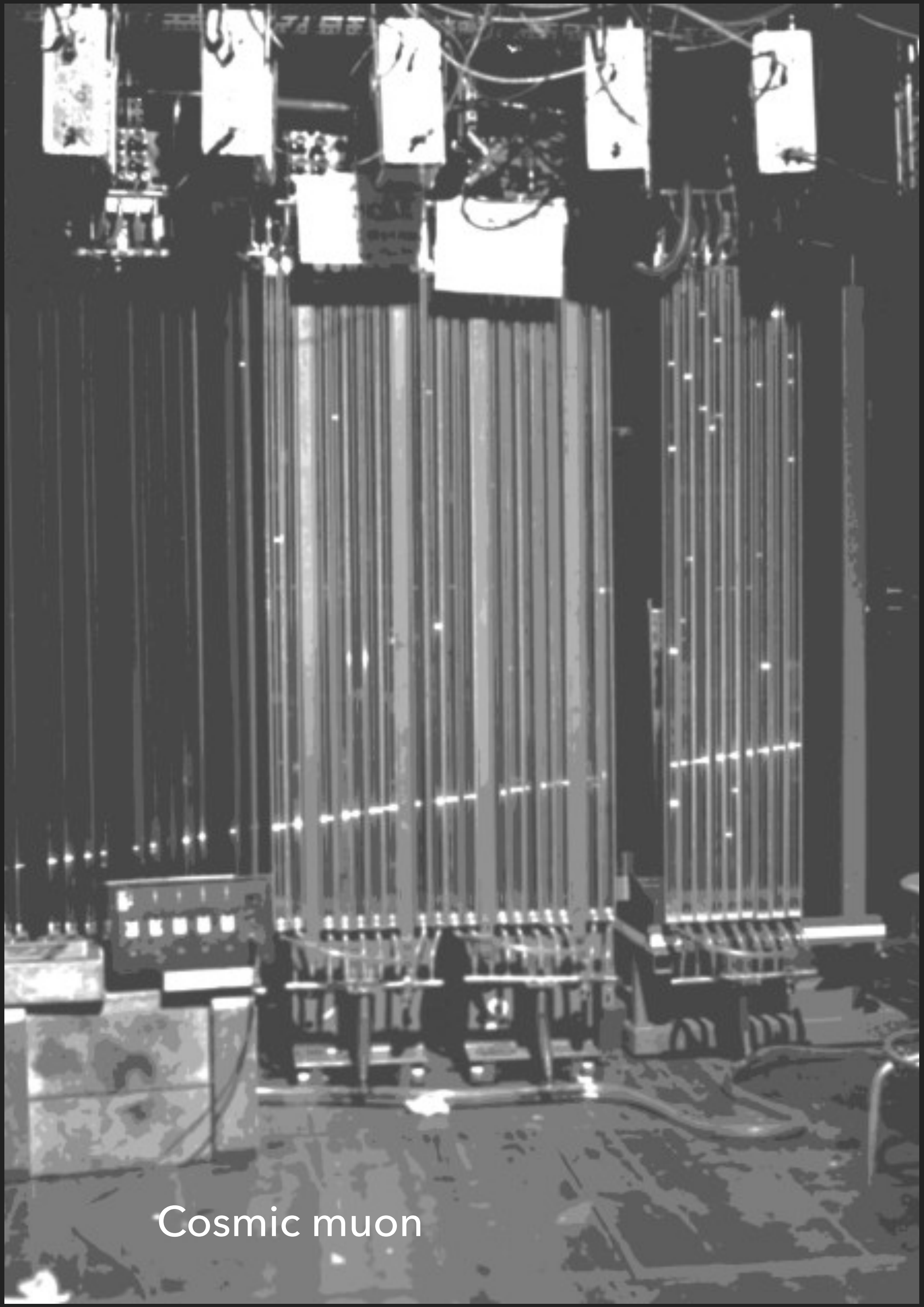
BUBBLE CHAMBERS (2)

- **Significant** time and effort involved:
  - Detectors needed to be cycled for each photo, which takes **time**
  - And scanning such photos was a manual operation, involving teams of people on 24 hour shifts
  - CERN article: "Big European Bubble Chamber (BEBC), which started operation at CERN in 1973, took 6.3 million pictures during its 11 years of service"



SPARK CHAMBERS

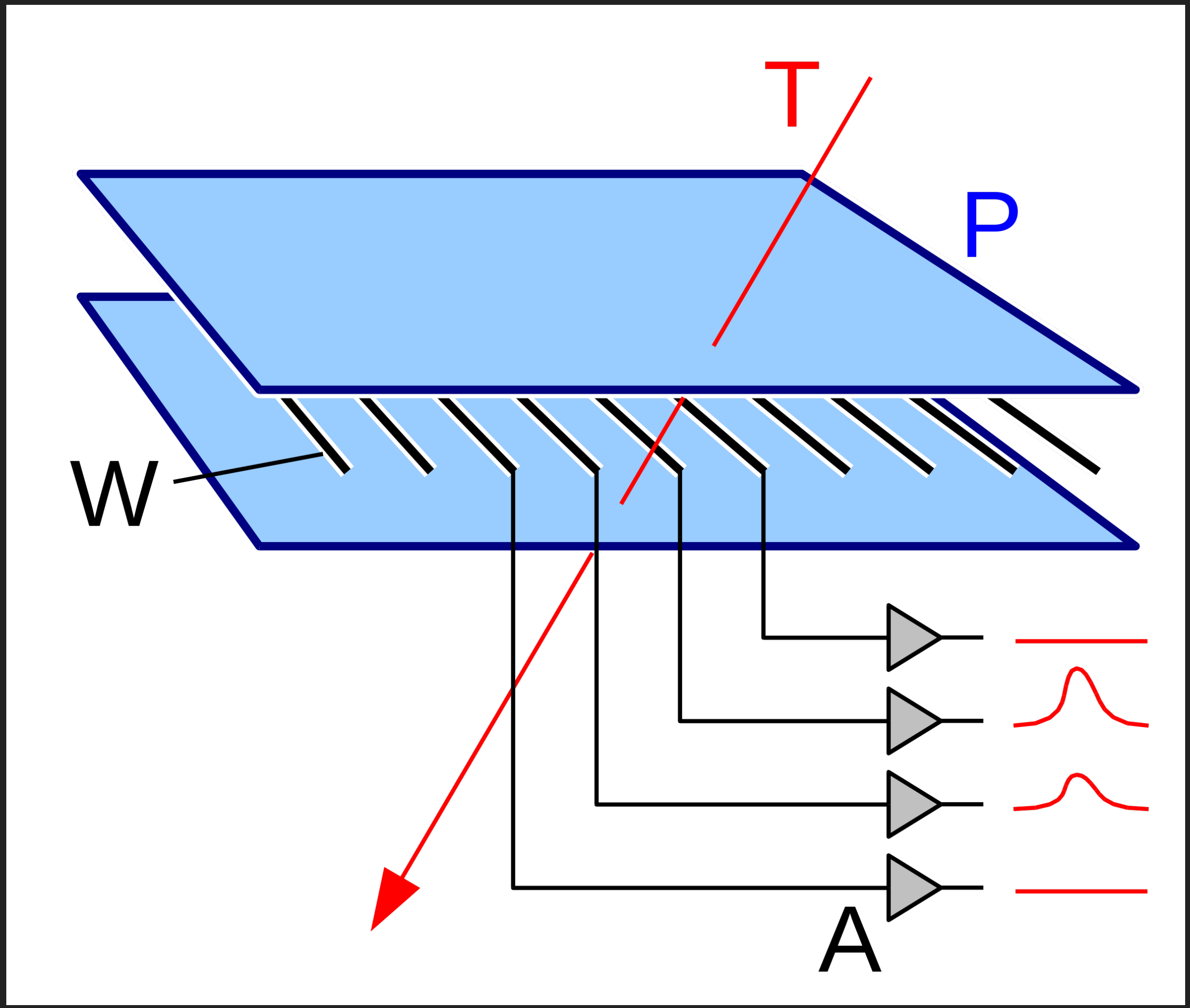
- Much faster, since you don't need to cycle the chamber (for instance, with bubble chambers)
- Particles pass through inert gas
- High voltage across plates of chambers causes spark to form
- However, less resolution than bubble chambers (i.e. not as precise)
- And still require photographs…



https://cds.cern.ch/record/40299

MODERN ERA

- In 1968 French scientist Charpak developed the "multiwire proportional chamber"
  - 1992 Nobel prize in physics
  - Samuel Ting's discovery of the J/psi particle and Carlo Rubbia's discovery of the W and Z particles, which won Nobel Prizes in 1976 and 1984, respectively, involved the use of multiwire chambers;
- **Revolutionised** particle physics - detection now quick, automated and electronic
  - Whilst the detectors we have now are vastly more capable, the **principles** remain similar
- In particular: we need to process the data with computers. Photographs no longer possible. **We need event displays**.

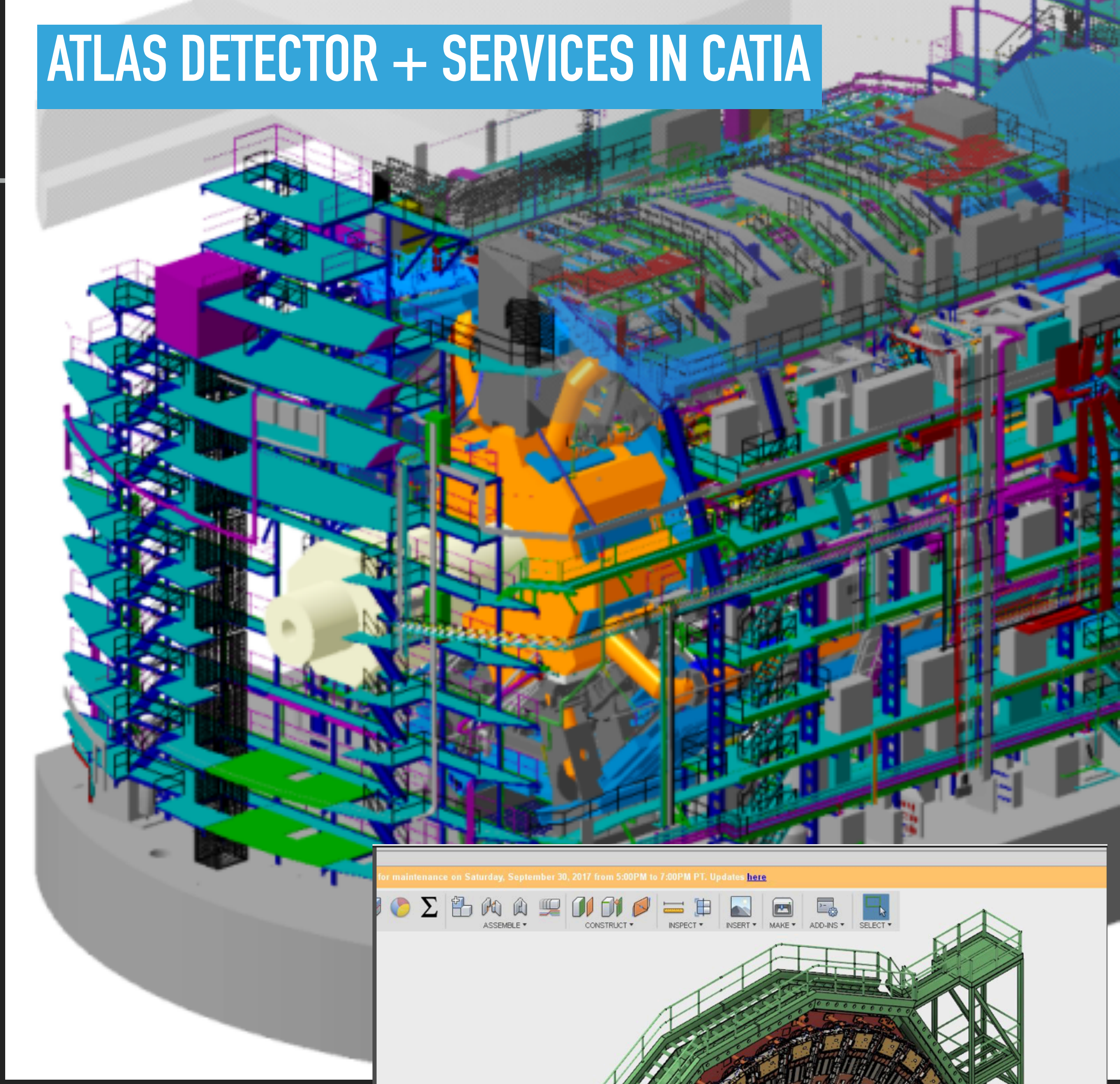


1979 – GLUON DISCOVERY (DESY)

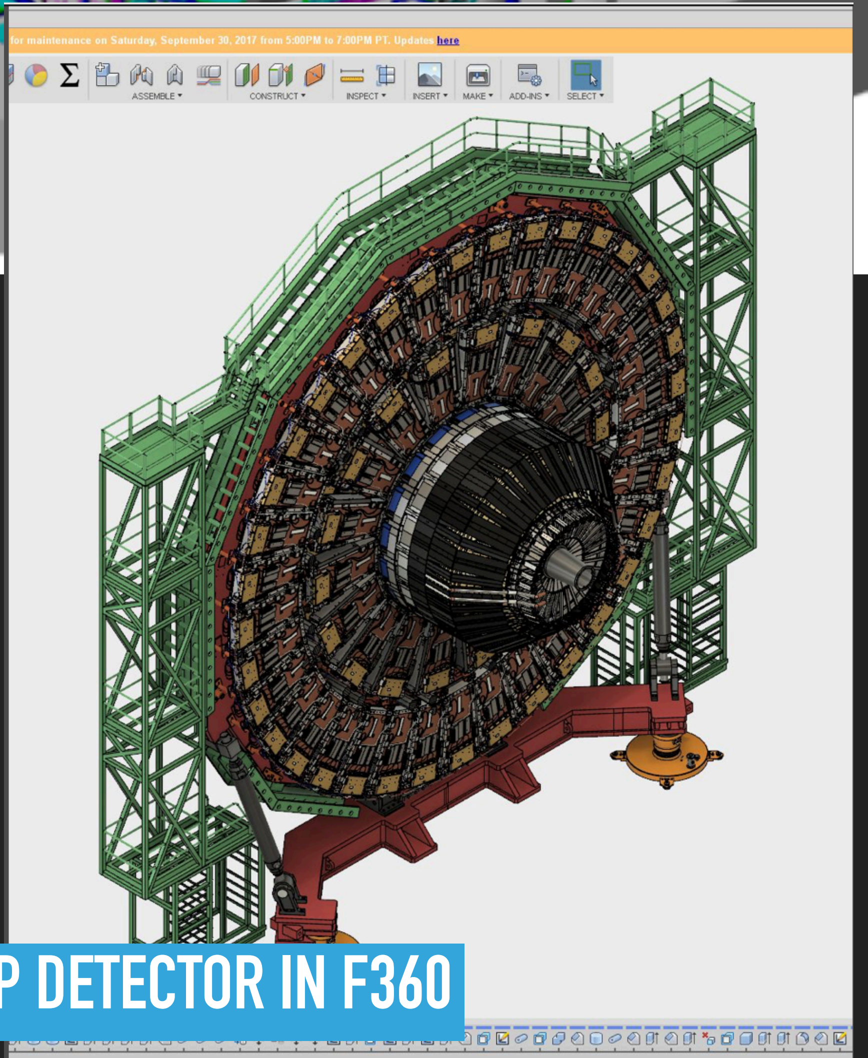
GEOMETRY DEBUGGING

GEOMETRY DEBUGGING & DEVELOPMENT

- Need to
  - Accurately show the geometry as
    - Built (i.e. from CAD)
    - Simulated (which is likely a simplification of the above)
    - Used in reconstruction (which might be further simplified still)
  - Allow easy navigation through the detector, enable disable chambers etc
  - If possible, indicate problems such as **geometry clashes**
- Why not use off the shelf tools?
  - We do! But…
    - We often have our own detector description languages and libraries e.g. GeoModel, DD4HEP
    - And ideally we have something that works with the same description as the stuff we're trying to debug

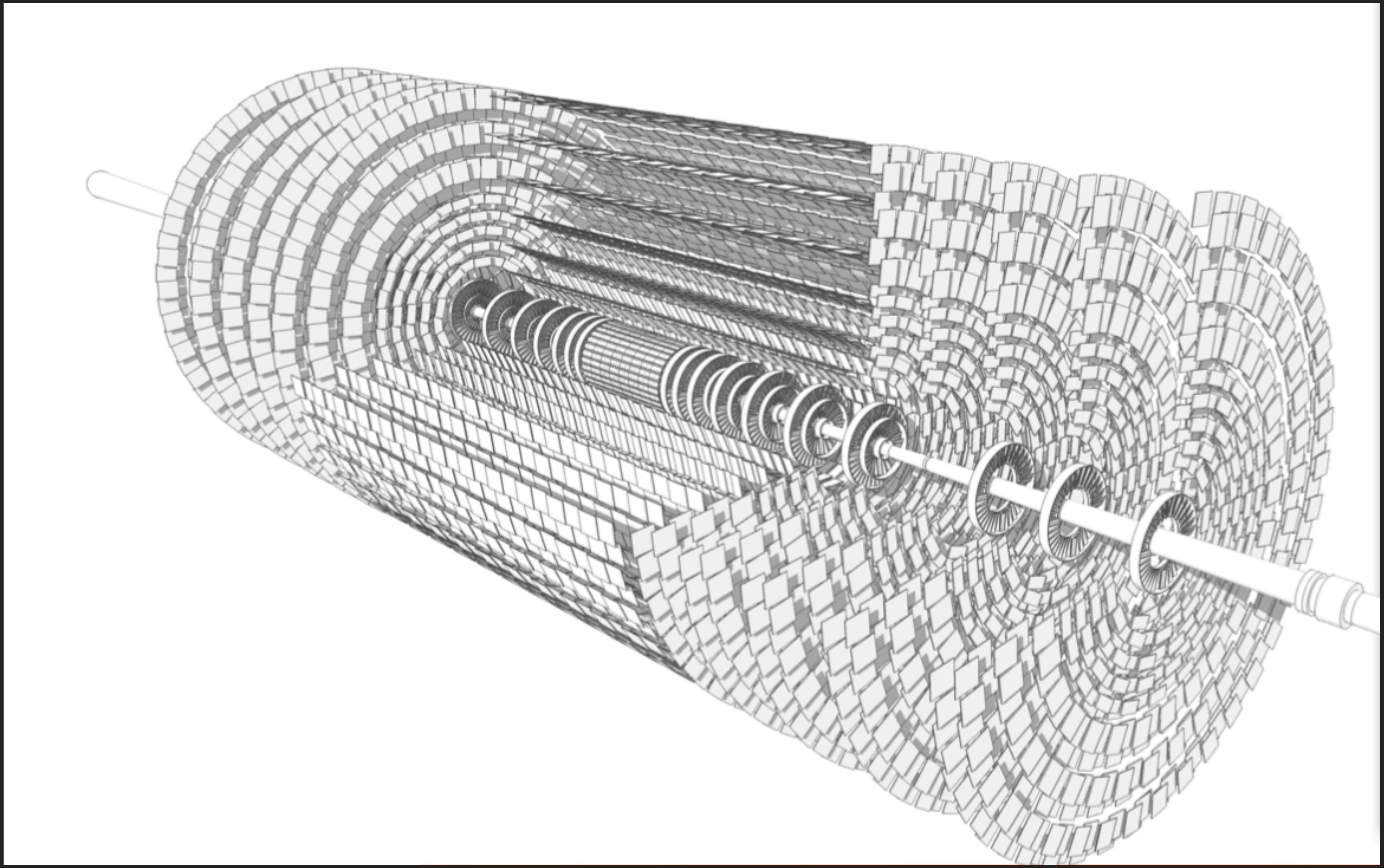


ATLAS DETECTOR + SERVICES IN CATIA



CMS MUON ENDCAP DETECTOR IN F360

CMS as rendered by Sketchup



https://indico.cern.ch/event/617054/contributions/2520106/attachments/1435509/2207210/tai_20170328_HSFVisualization_SketchUp.pdf

MONITORING PERFORMANCE

MONITORING PERFORMANCE

- Modern particle physics detectors are hugely complex machines
  - Millions of channels of monitoring data (e.g. voltages, temperatures, cooling flow rates, humidity, gas composition), in addition to the physics data
- Event displays can visually show problems e.g. empty chambers, missing layers etc
  - In practice, only part of the toolkit

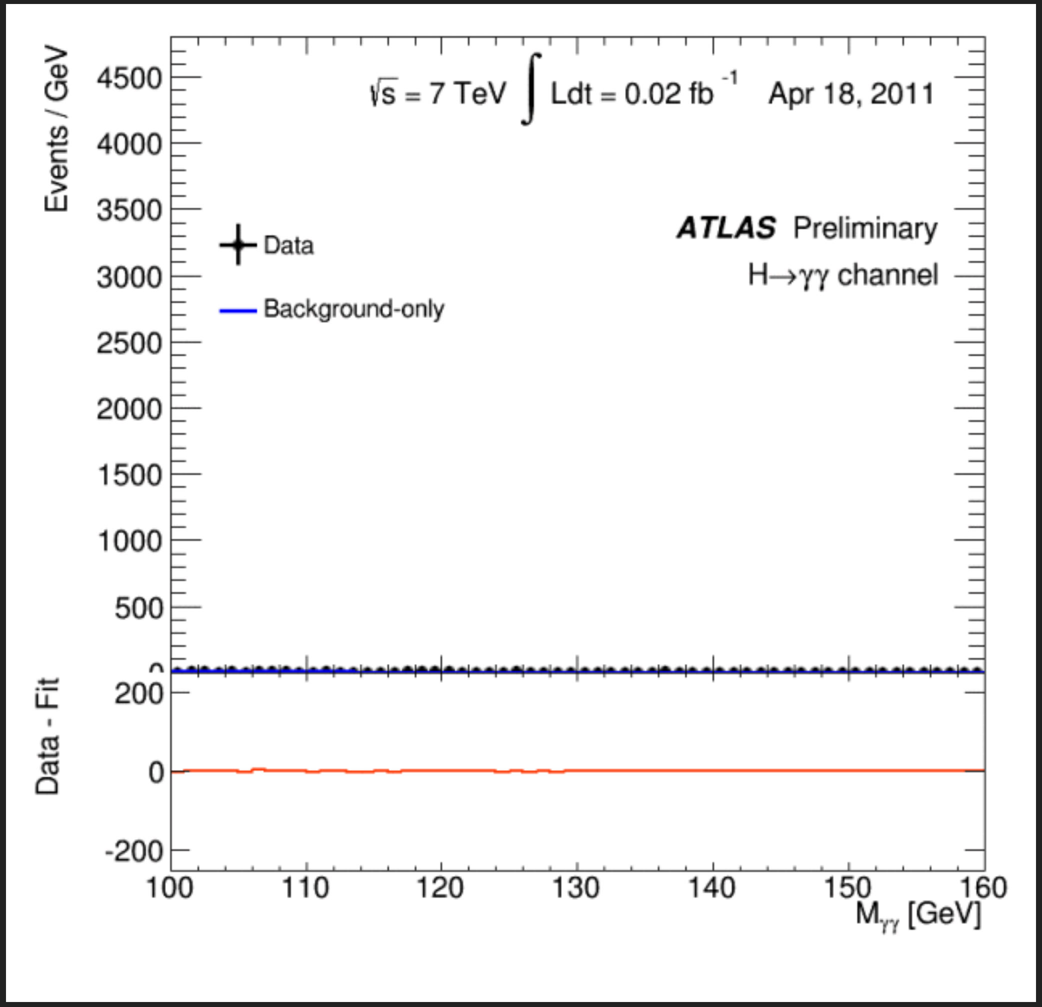
CDF control room

ATLAS control room

VISUALISING PHYSICS

VISUALISING PHYSICS

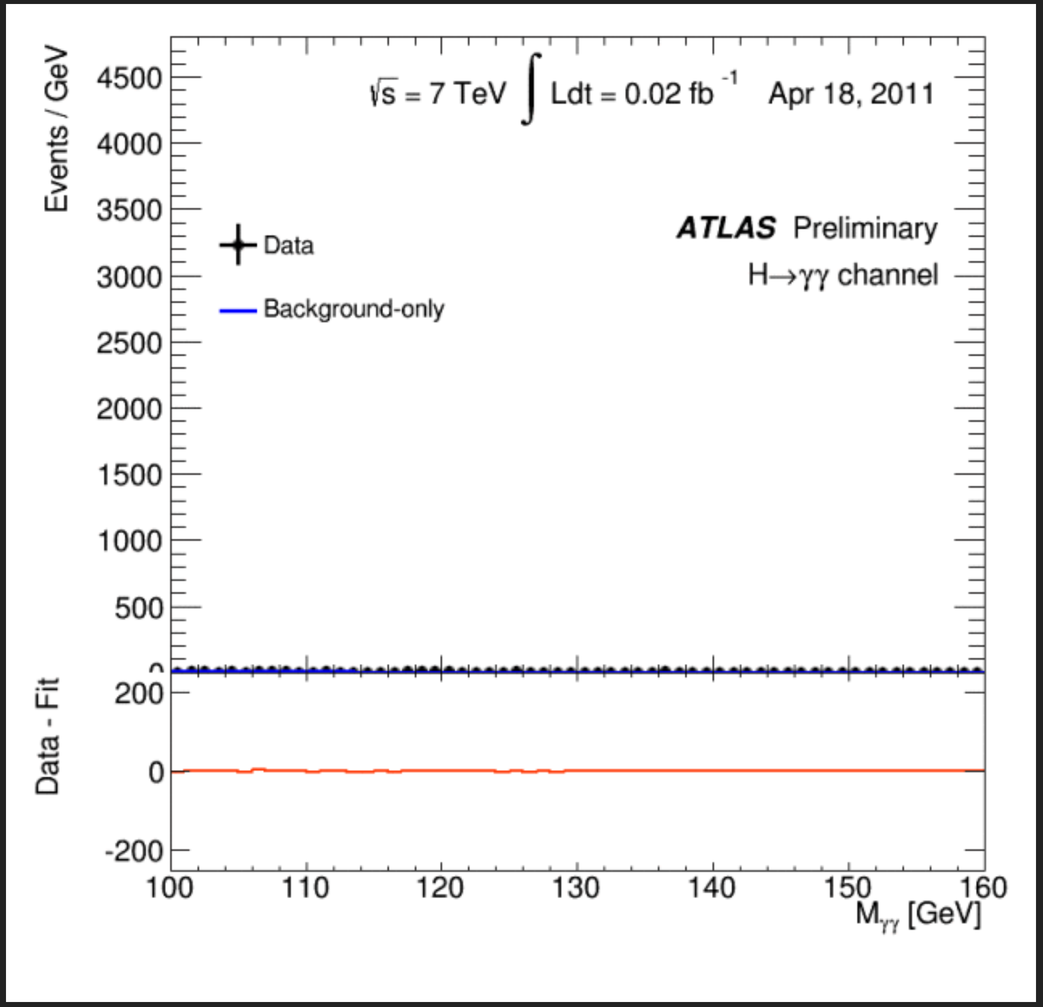
- In HEP we're typically not making discoveries from one event, rather it takes a **lot** of data



[Link](#)

VISUALISING PHYSICS

- In HEP we're typically not making discoveries from one event, rather it takes a lot of data
- Nevertheless we **DO** examine single events:
  - When we first get hints of something exciting to try to make sure we're not making a stupid mistake
  - To try to understand problems with an **analysis**
    - Why don't we find high quality muons in this region?
    - Why is my isolation cut not working?
    - Etc

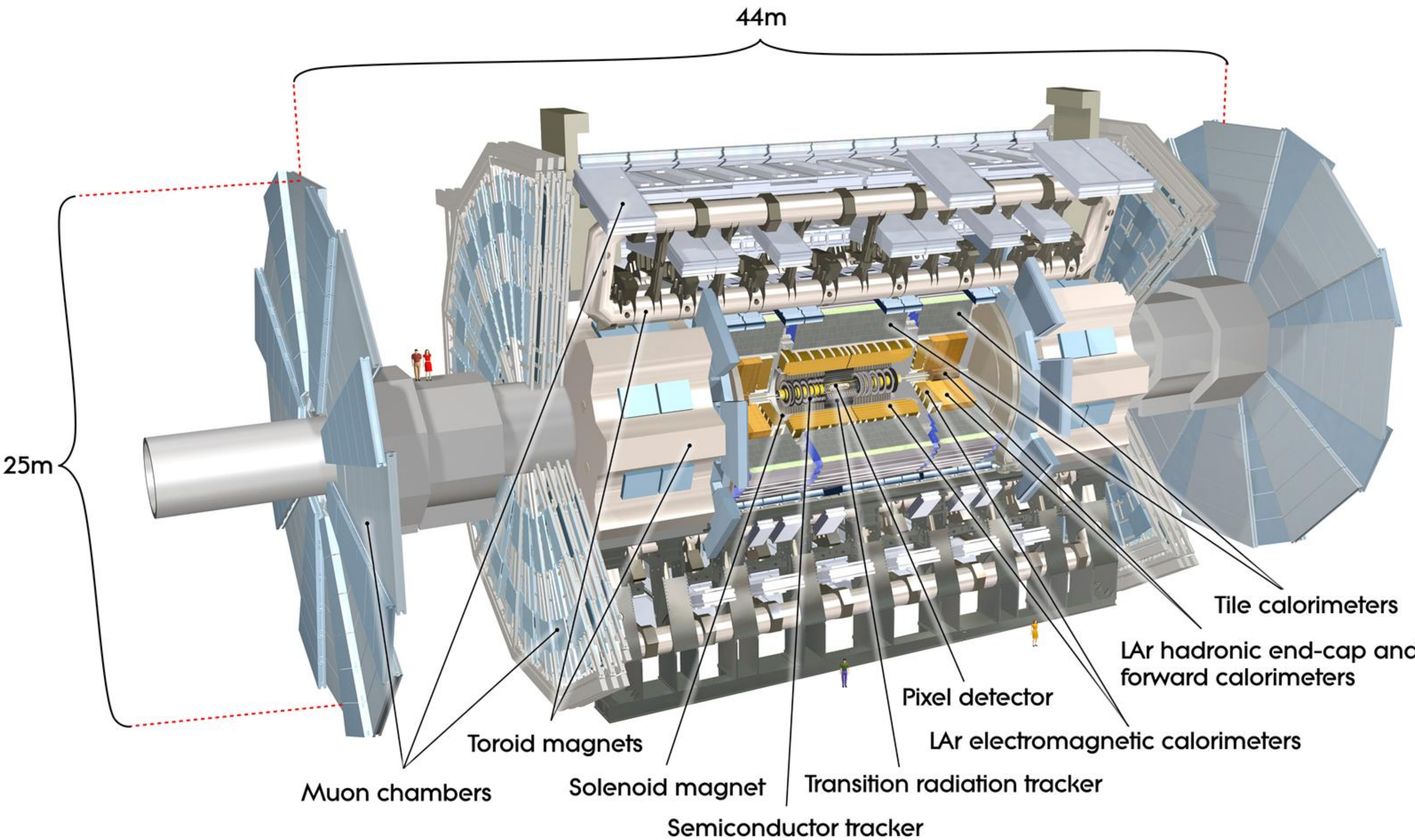


HOW TO REPRESENT PHYSICS DATA

- A reminder that energy in a typical LHC collision is roughly equivalent to a couple of mosquitos colliding
  - We are talking about things that are **tiny** (both in scale and energy)
  - But which happen incredibly fast
- Often, not even analogous to something humans would ever see
  - So, use visual shorthands
- The ideal is that a layperson can intuitively understand much of what what is being shown, but a physicist can see the type of physics process happening
  - *Balance between accessibility and precision*
  - For outreach, focus more on *former*, for plots for physics papers, the *latter*

WHAT DO WE WANT TO SHOW?

- A few key problems here:
  - How do we visualise the **detector response**?
  - How do we visualise the **reconstructed physics** (whether from simulation?
- Bonus!
  - If simulated, how do we use ‘truth’ to show bugs in our simulation or reconstruction technique?

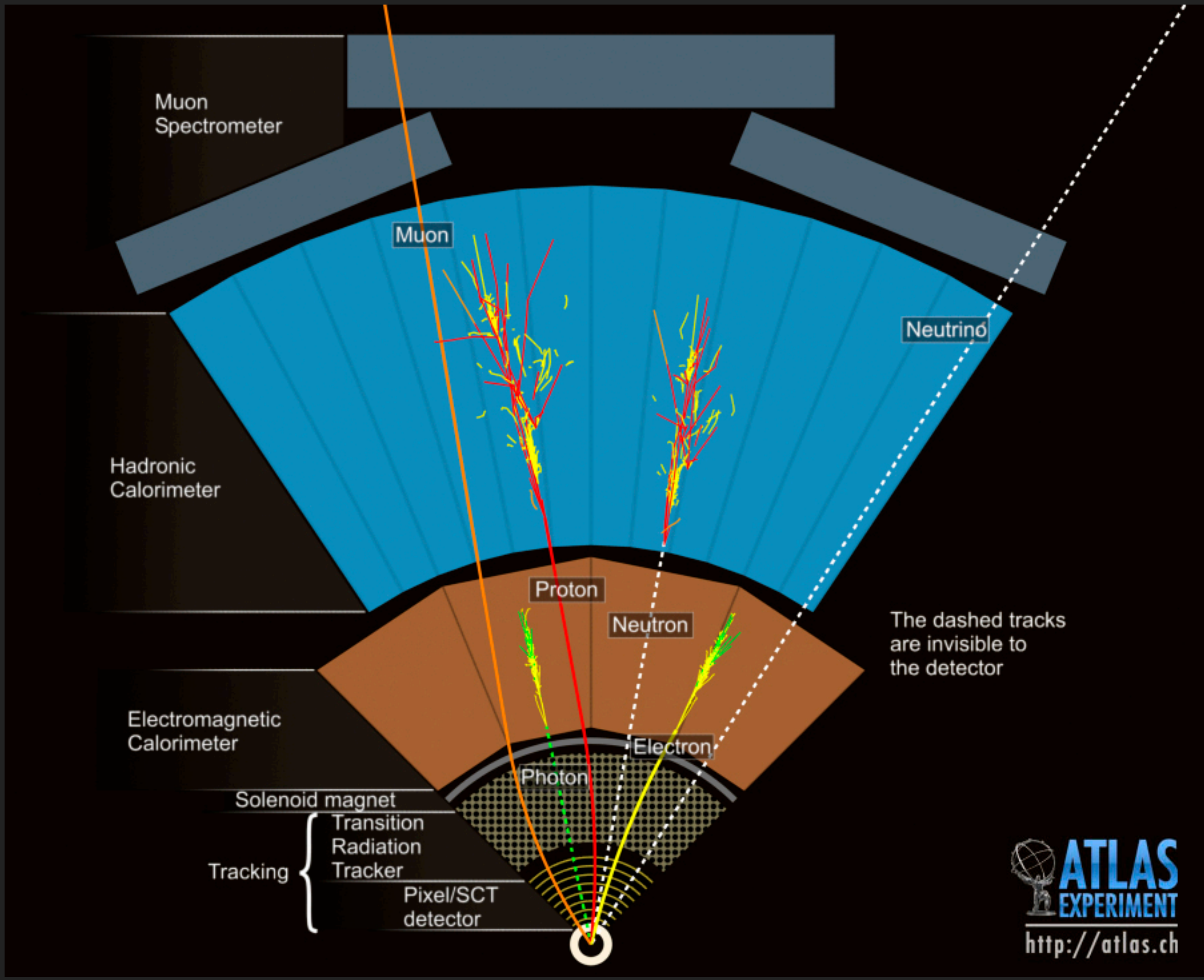

44m
25m
Tile calorimeters
LAr hadronic end-cap and
forward calorimeters
Pixel detector
LAr electromagnetic calorimeters
Toroid magnets
Muon chambers
Solenoid magnet
Transition radiation tracker
Semiconductor tracker

DETECTOR RESPONSE

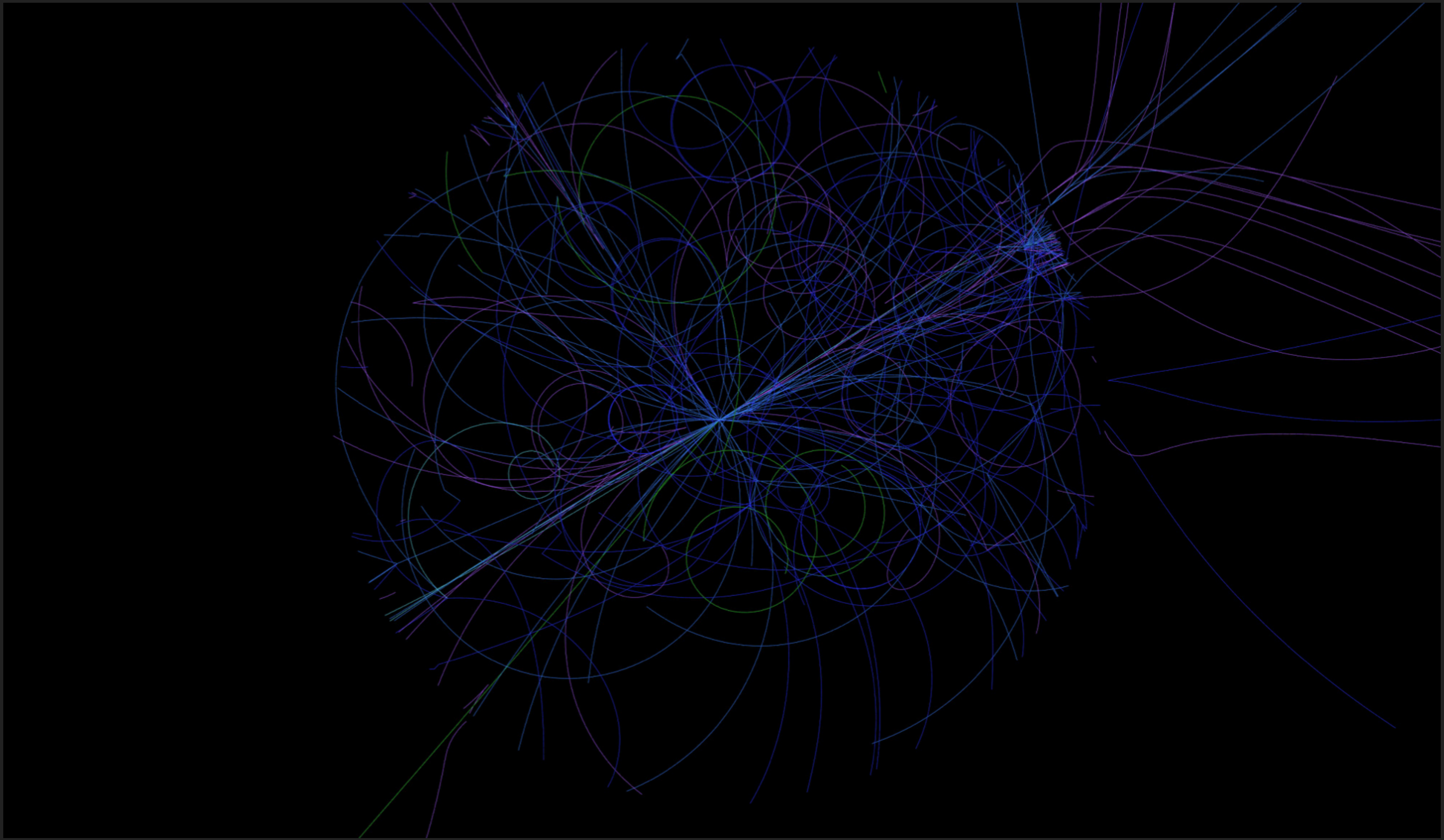
- Some types of data to show:
  - **Measurement** in space from e.g. silicon detector
    - Could represent with a point or line in space (depending on whether pixel or strip)
    - Could also try to show charge deposition, time over threshold etc etc
  - **Measurement** from something more complex
    - **Drift tube** - measures the time taken for a charge produced by passing track to reach central wire
  - **Calorimeter**
    - Show energy deposition in space

VIEW OF PHYSICS / RECONSTRUCTED QUANTITIES

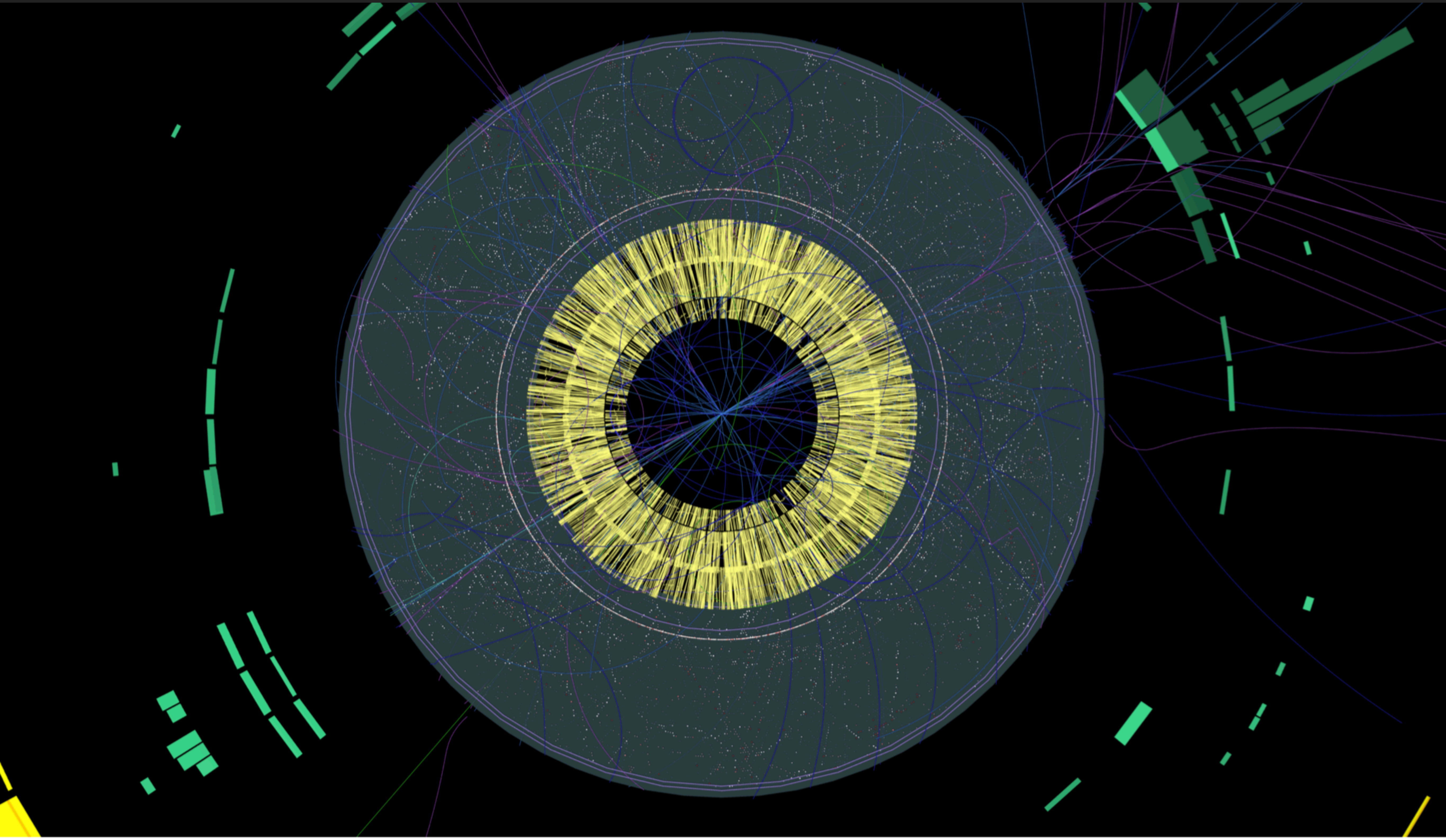
- Types of physics we might want to see
  - **Tracks** - paths of charged particle in detector
  - **Energy depositions** e.g. in a calorimeter
  - **Vertices** - where did tracks come from
  - **Jets** - areas of high activity in detector
  - **Missing energy** - hard to spot by eye, but could show result of reconstruction



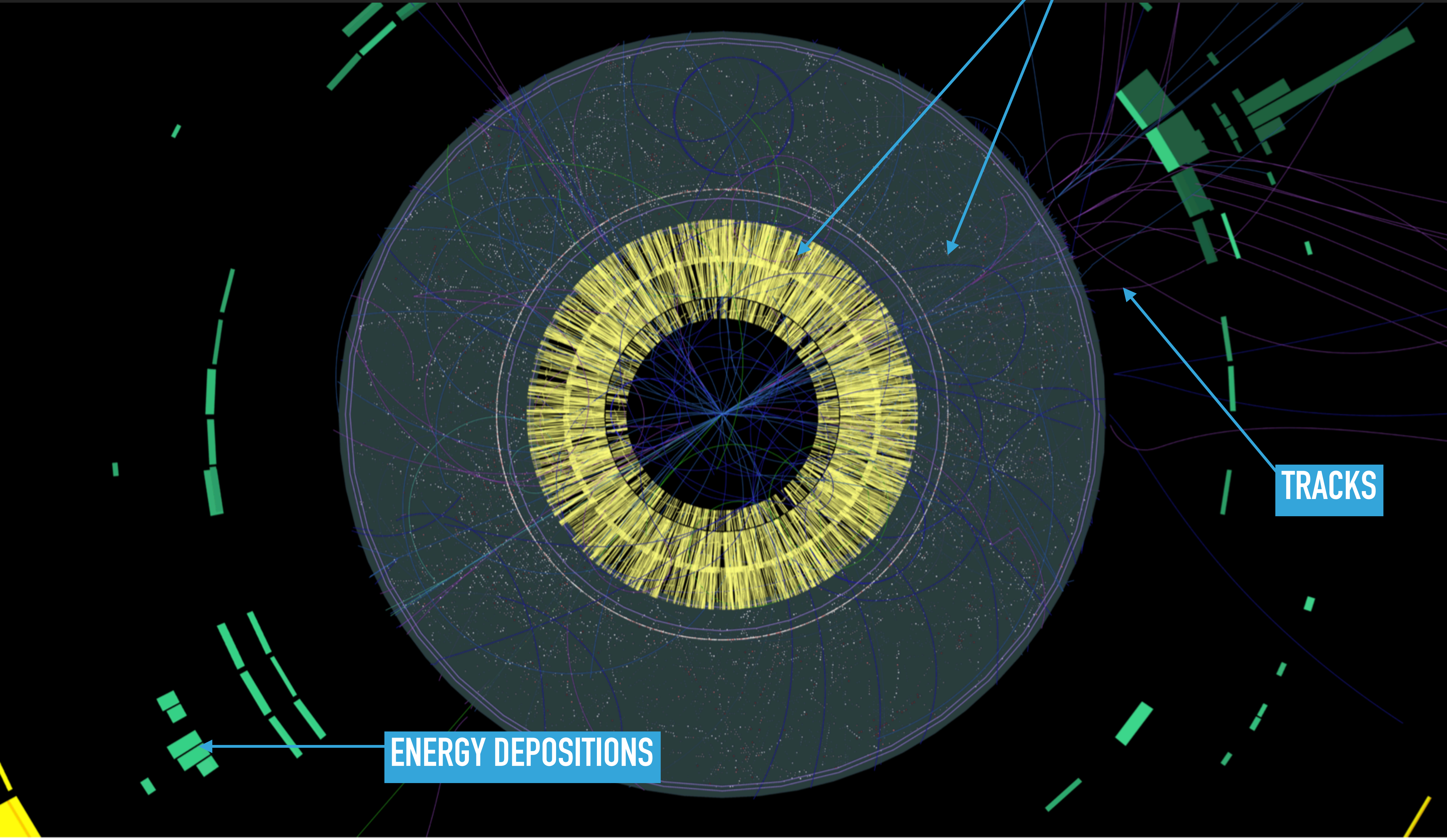
SIMULATED EVENT



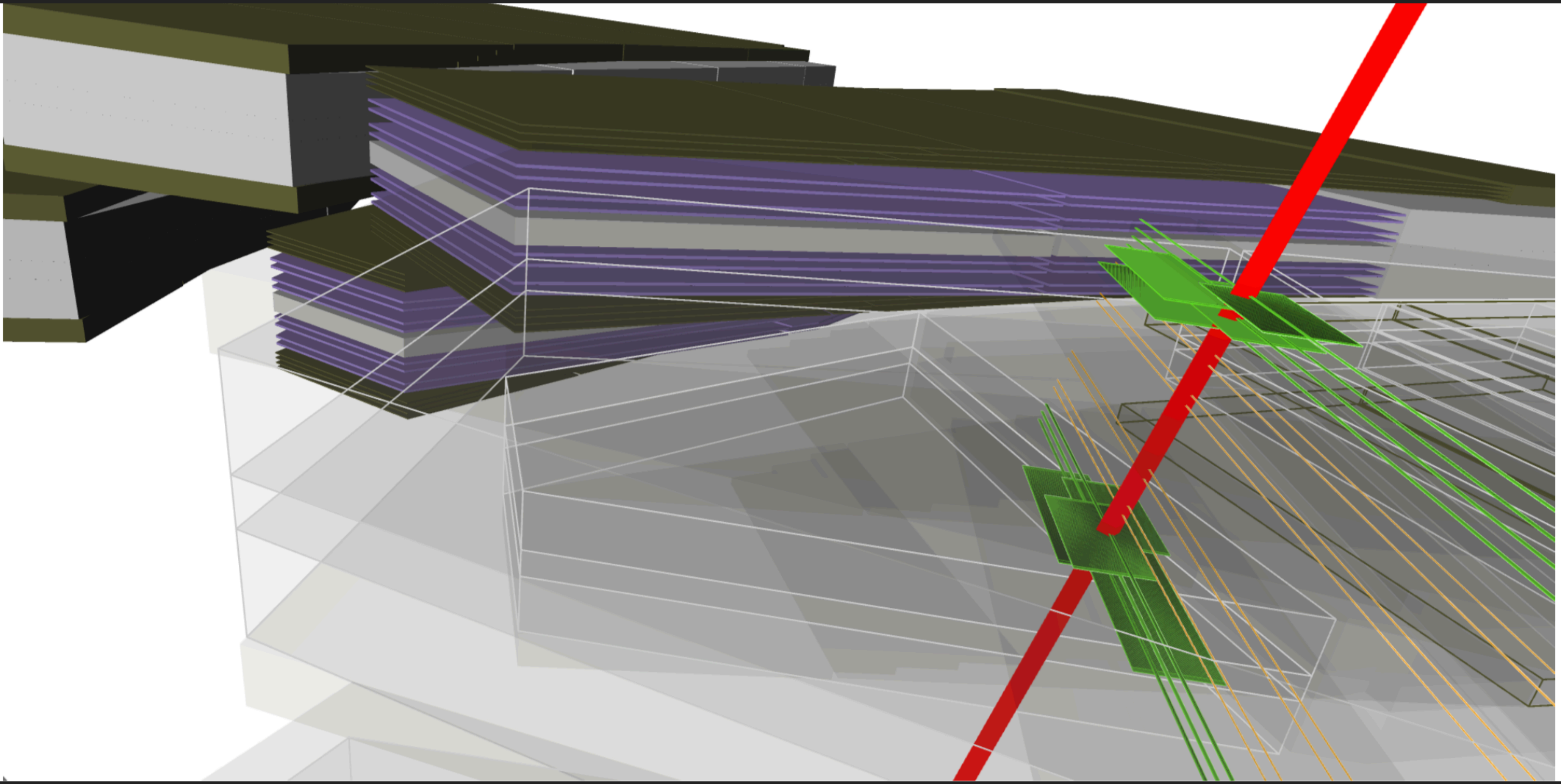
SIMULATED EVENT - OVERLAY DETECTOR RESPONSE



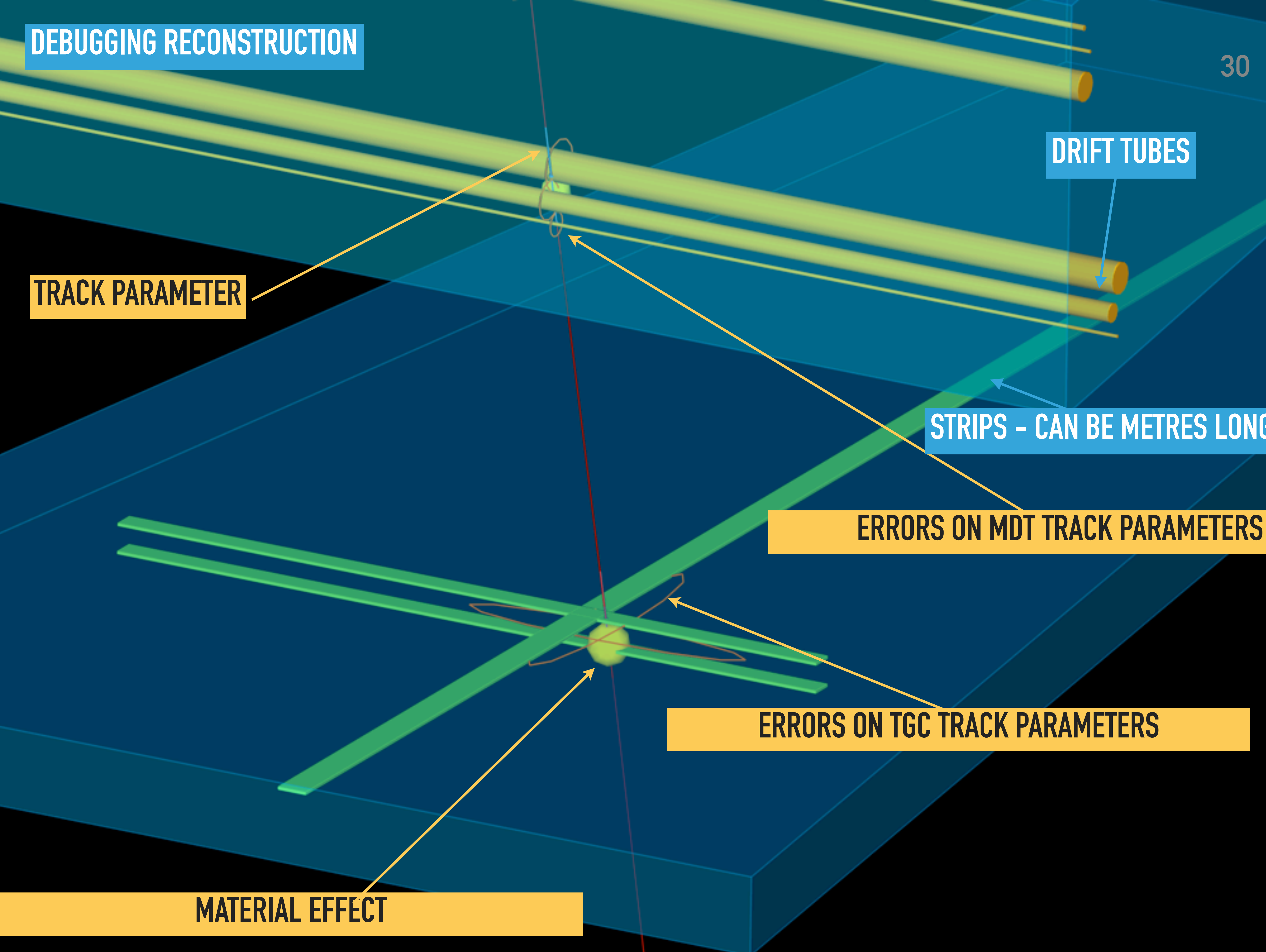
SIMULATED EVENT – OVERLAY DETECTOR RESPONSE



DEBUGGING RECONSTRUCTION

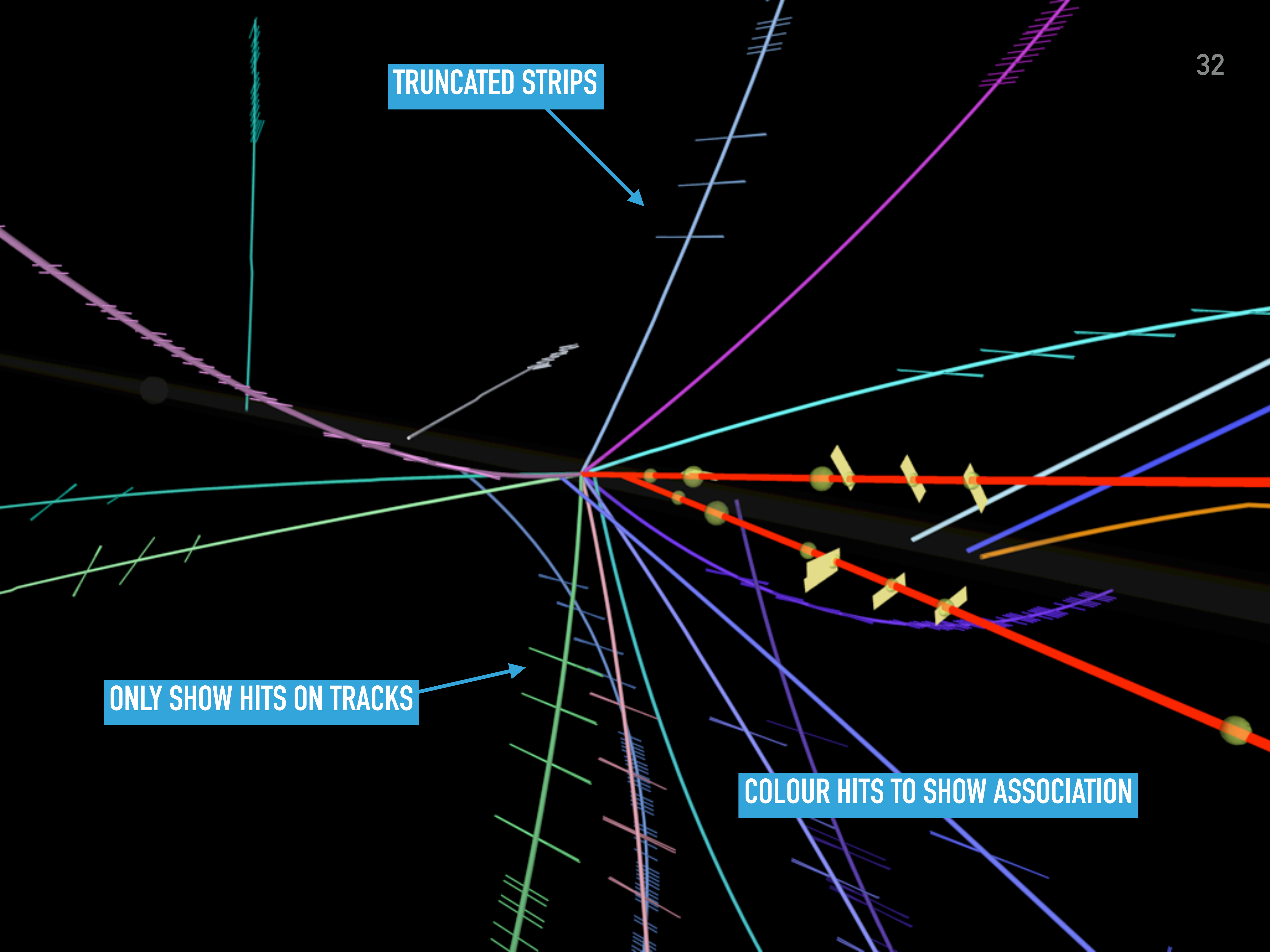


DEBUGGING RECONSTRUCTION

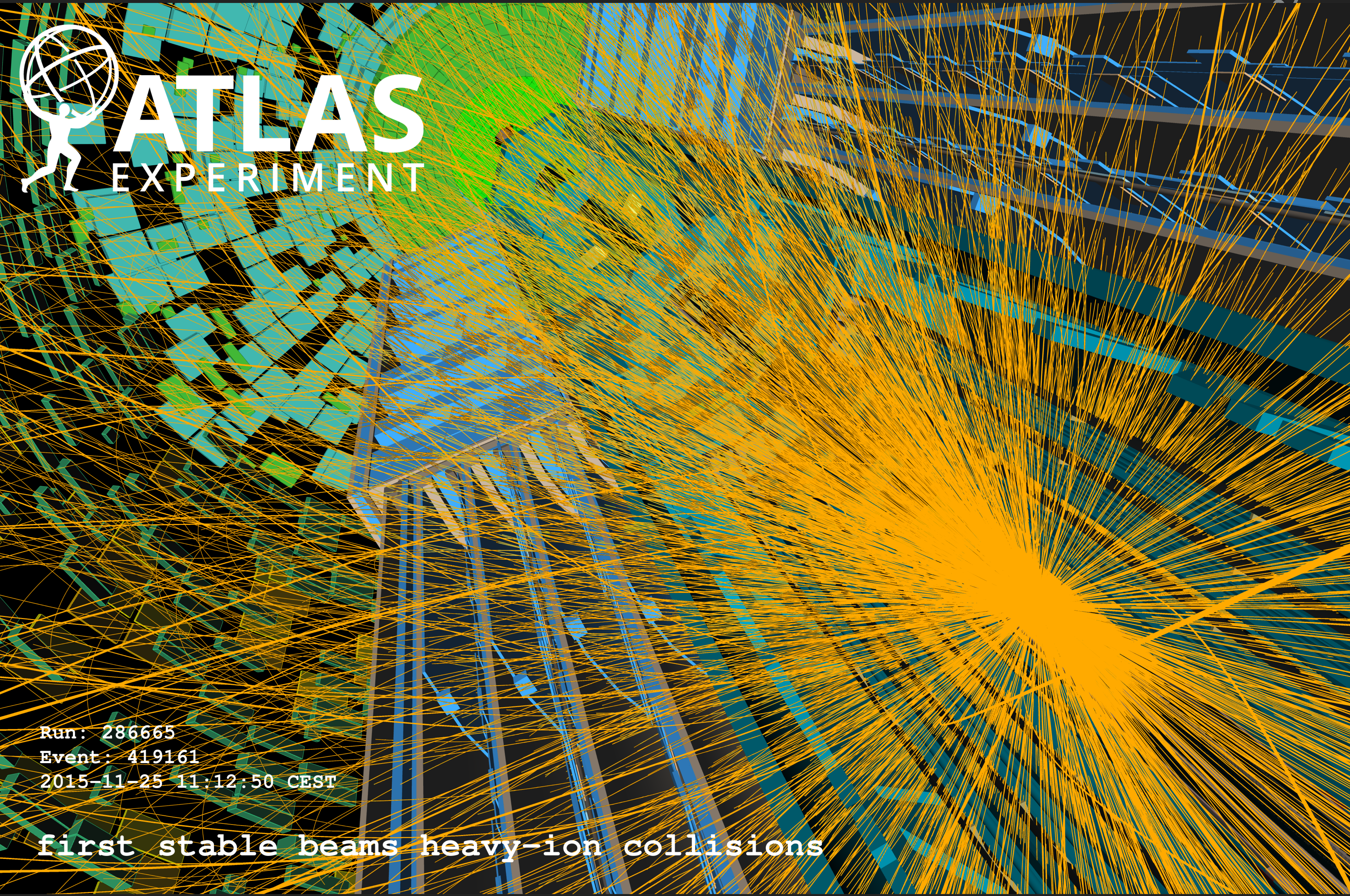


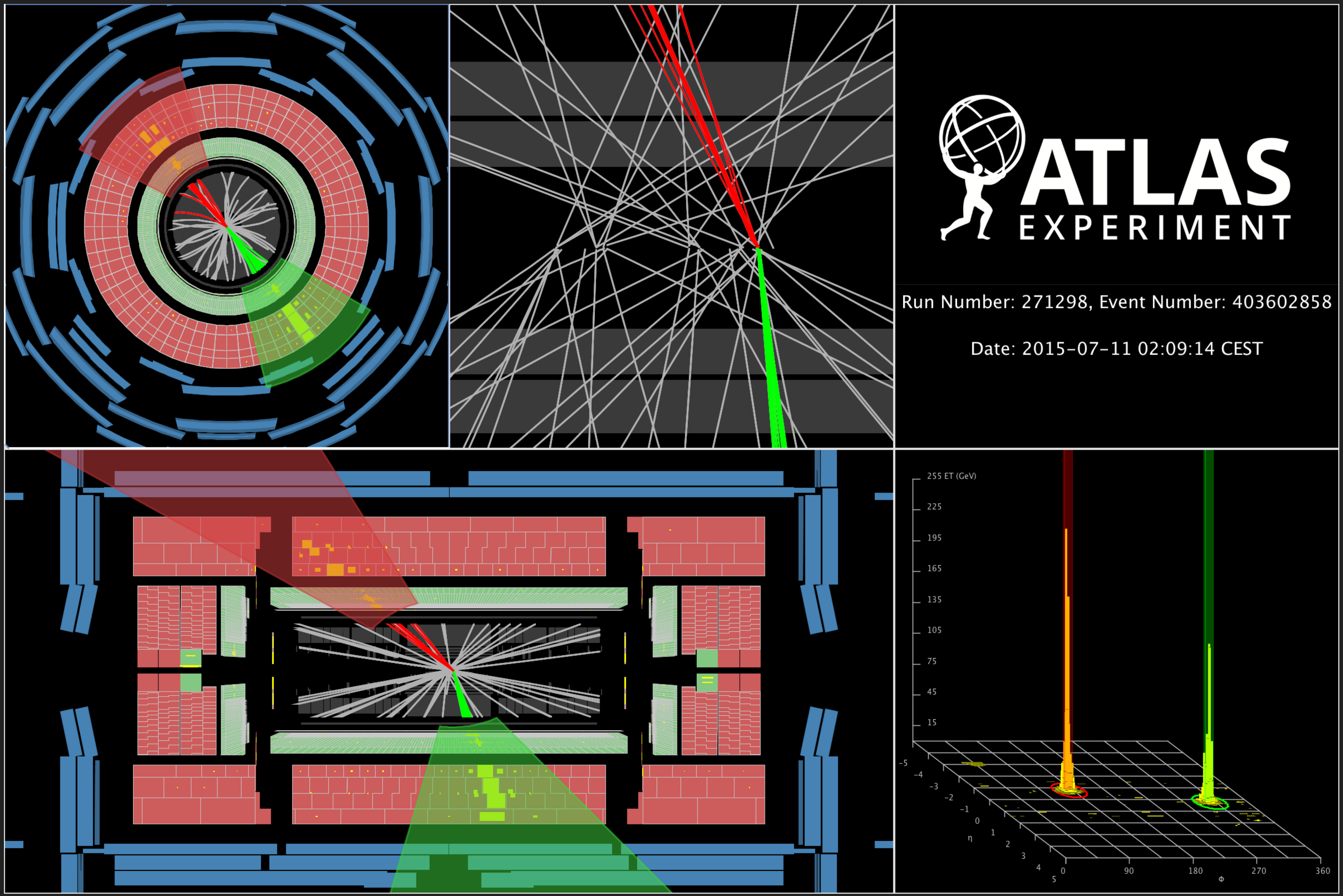
CUTS (OR FILTERS)

- We have talked a bit about what we want to show - often it's as important to talk about what we DON'T want to show
- If there are thousands of tracks per event, how do we show the few which are interesting
- How do we hide parts of the detector which are blocking our view
- **Projections** - using natural symmetries of detector - are also very useful


TRUNCATED STRIPS
ONLY SHOW HITS ON TRACKS
COLOUR HITS TO SHOW ASSOCIATION

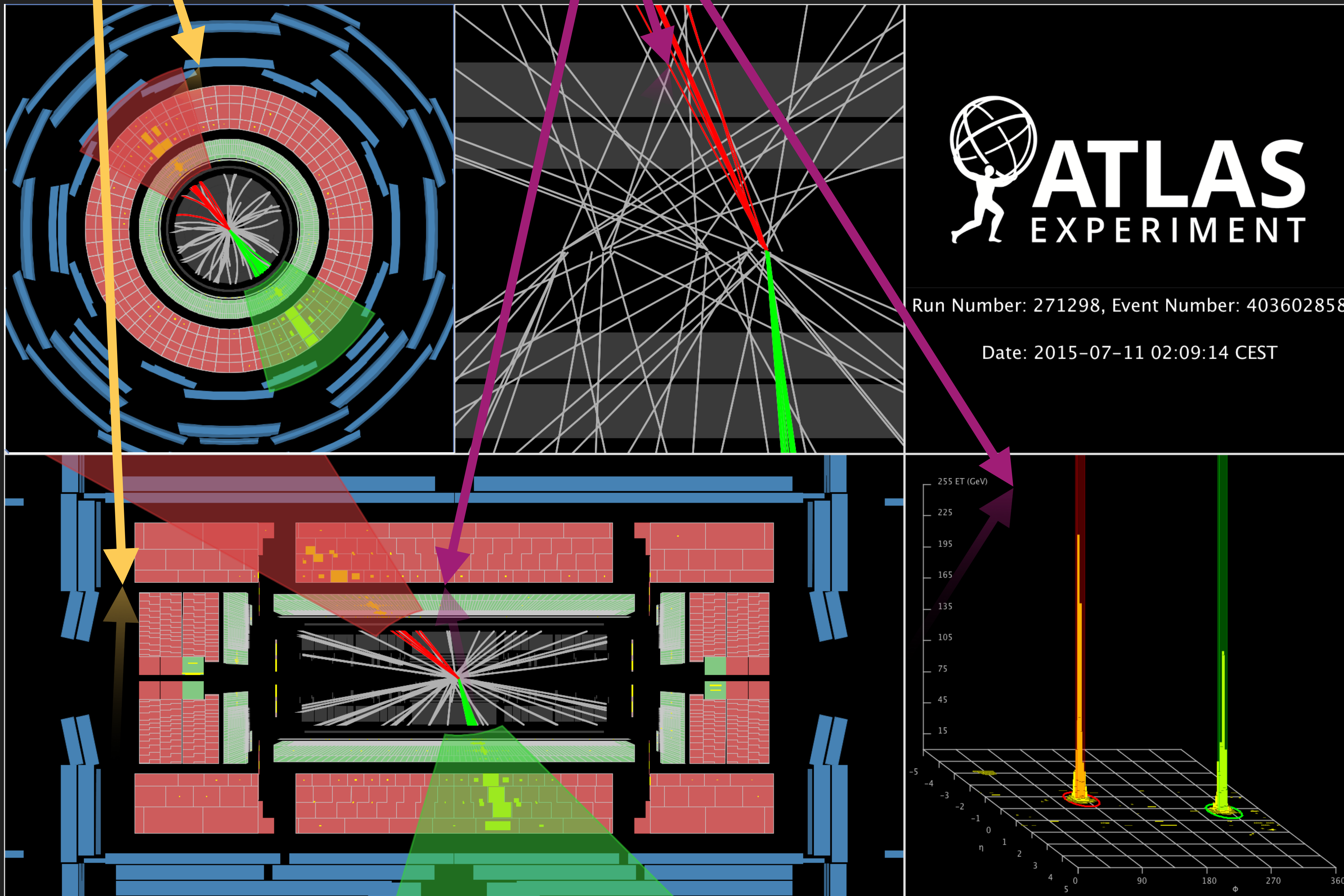
MORE EXAMPLES….


ATLAS
EXPERIMENT
Run: 286665
Event: 419161
2015-11-25 11:12:50 CEST
first stable beams heavy-ion collisions


ATLAS
EXPERIMENT
Run Number: 271298, Event Number: 403602858
Date: 2015-07-11 02:09:14 CEST
255 ET (GeV)
225
195
165
135
105
75
45
15
-5
-4
-3
-2
-1
0
1
2
3
4
5
η
0
90
180
270
360
Φ

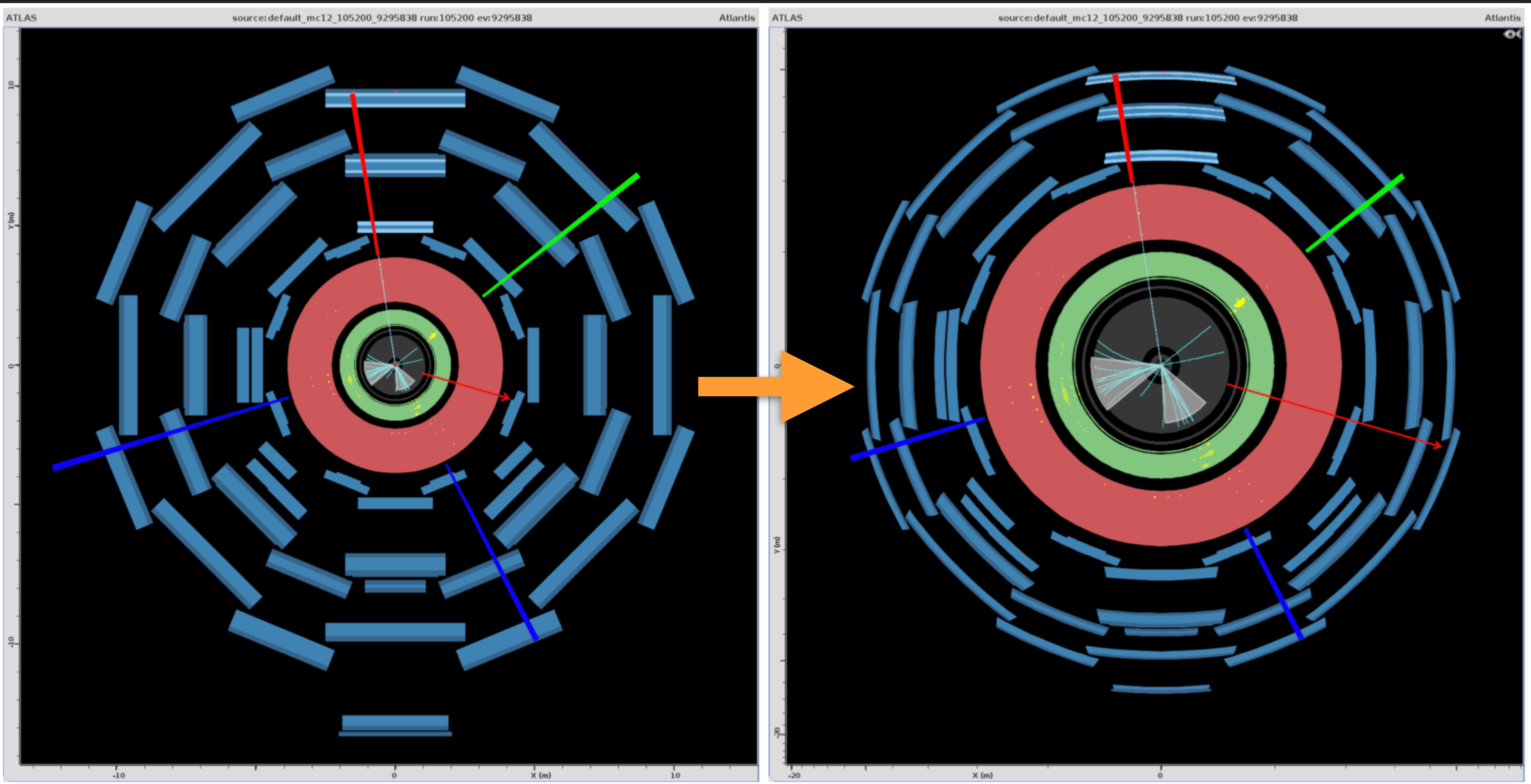
FISH EYE COMPRESSION

COLOUR BY JET - LINKS INFORMATION IN DIFFERENT VIEWS



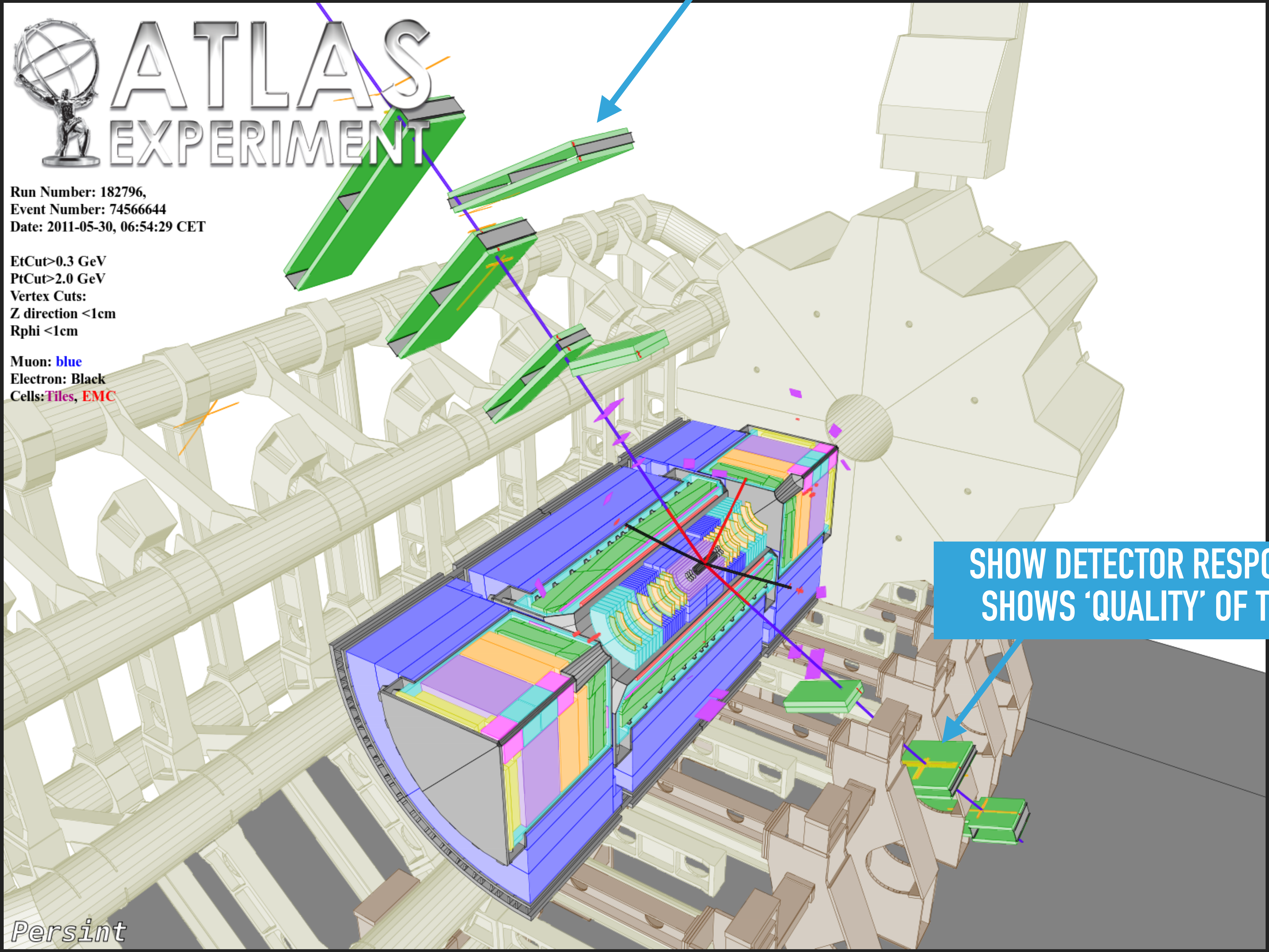
SOME SAME DATA WITH VARIOUS VIEWS/PROJECTIONS AT THE SAME TIME

Fish eye projection - weight object visibility by importance, whilst preserving symmetries

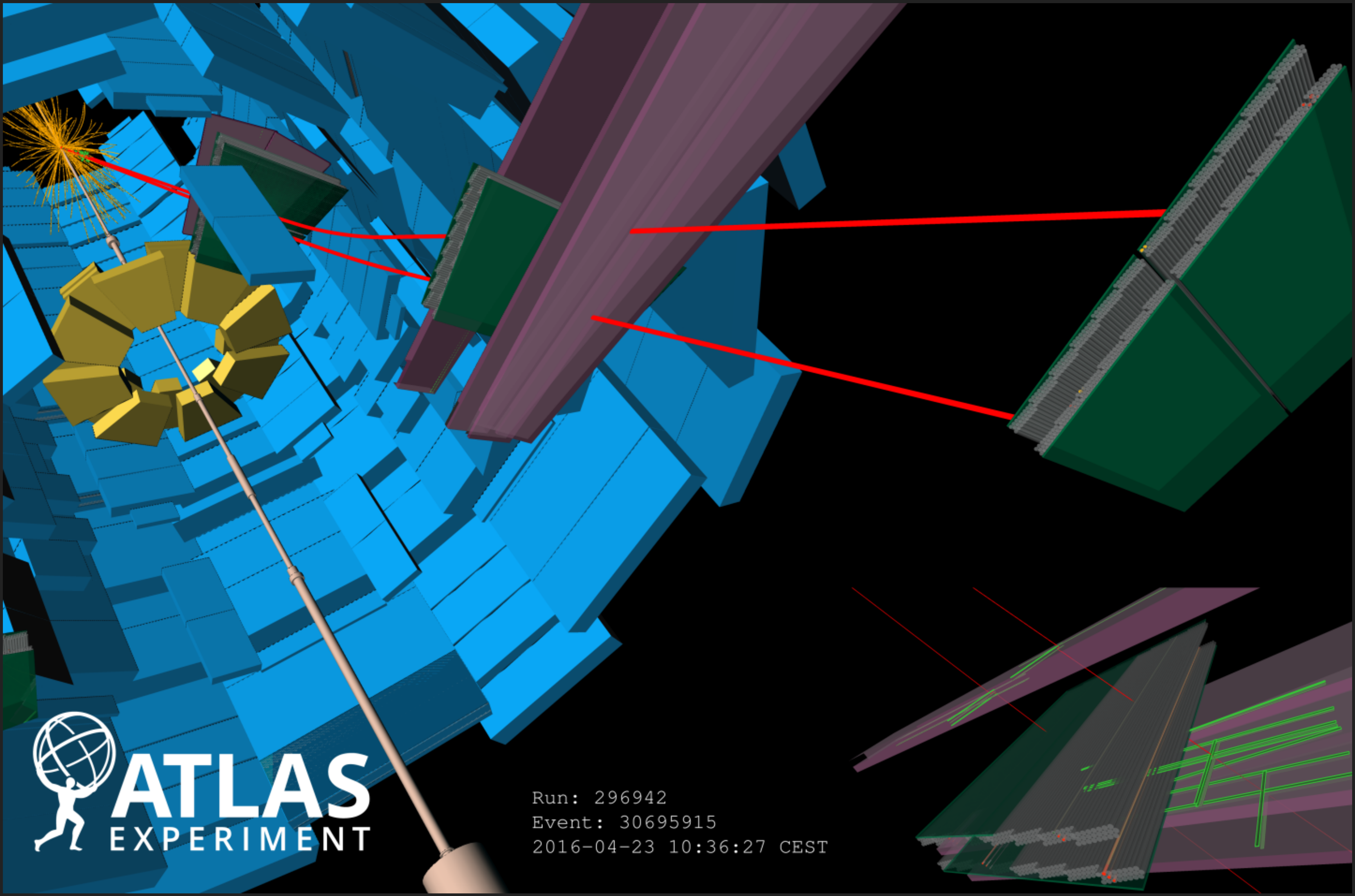


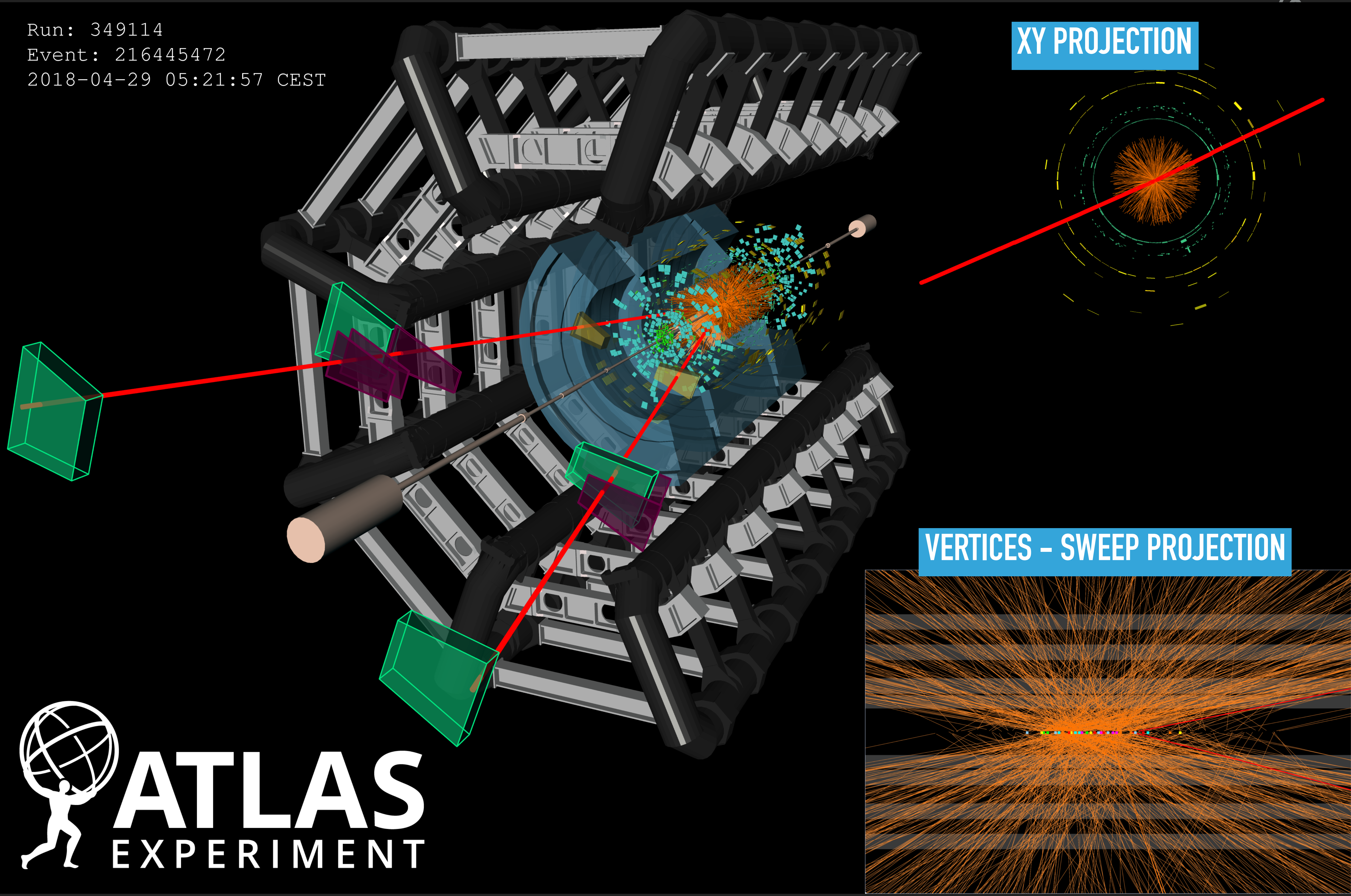
https://indico.cern.ch/event/617054/contributions/2520899/attachments/1435481/2207255/atlantis-20170328.pdf

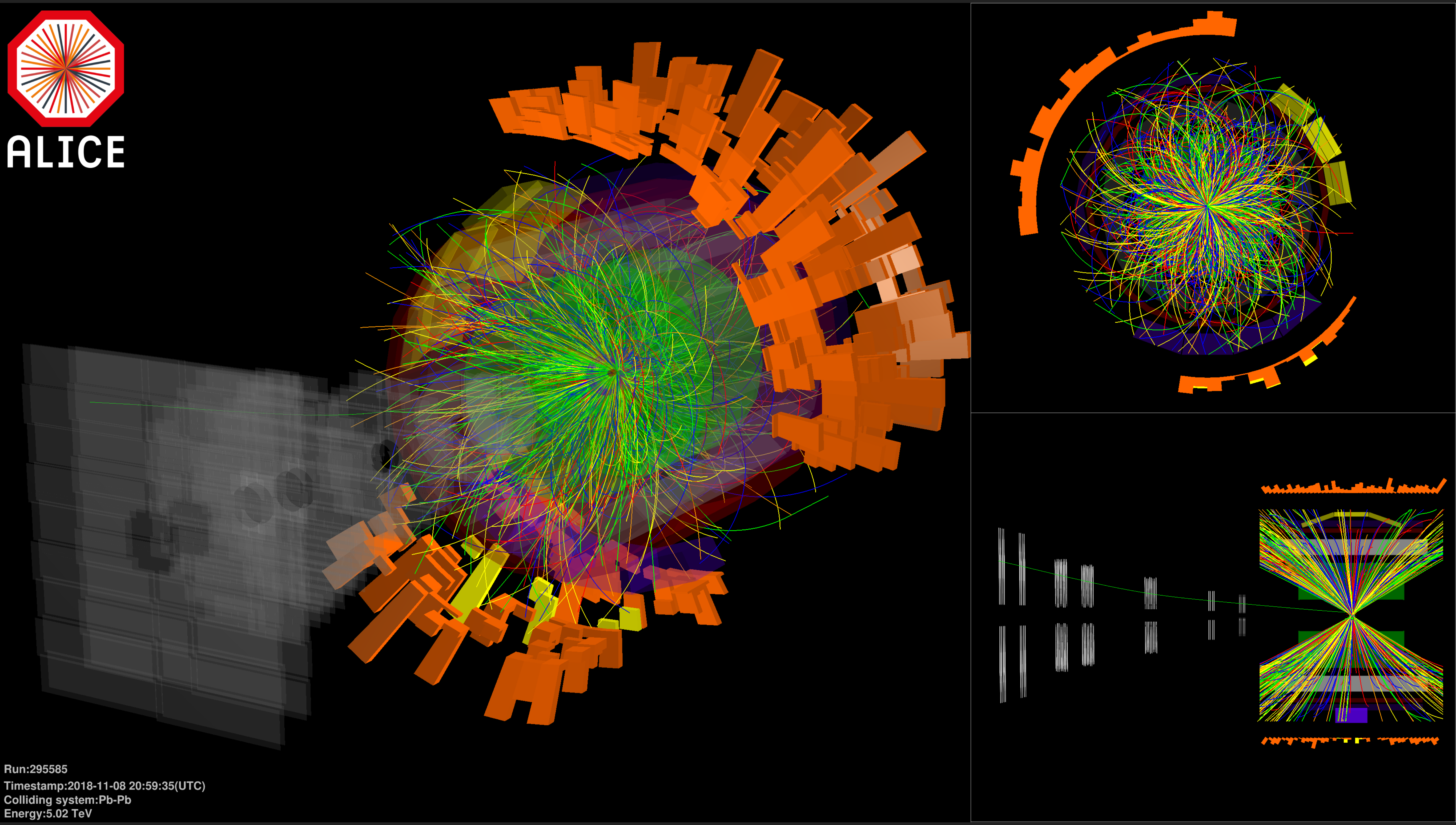
ONLY SHOW CHAMBERS WHICH ARE 'ACTIVE'



SHOW DETECTOR RESPONSE – SHOWS 'QUALITY' OF TRACK


ATLAS
EXPERIMENT
Run: 296942
Event: 30695915
2016-04-23 10:36:27 CEST


Run: 349114
Event: 216445472
2018-04-29 05:21:57 CEST
XY PROJECTION
VERTICES – SWEEP PROJECTION
ATLAS
EXPERIMENT



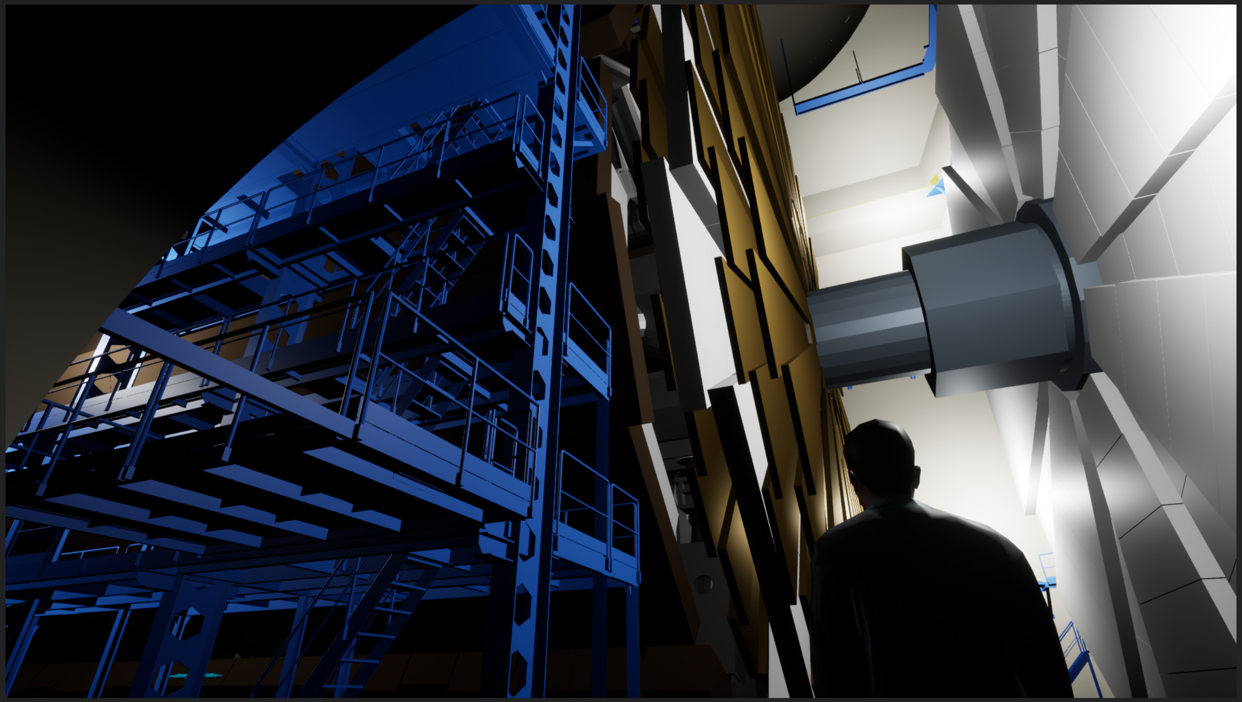
Collision of Pb ions at LHC with energy of 5.02 TeV per nucleon pair recorded by ALICE on 08.11.2018. The coloured lines represent the reconstructed trajectories of charged particles produced from the collision. The orange towers represent energy measured by the electromagnetic calorimeters. The green trajectory in the forward region corresponds to a muon traversing the dedicated spectrometer.

https://cds.cern.ch/record/2646381?ln=en

OUTREACH / PR

ATLAS RIFT

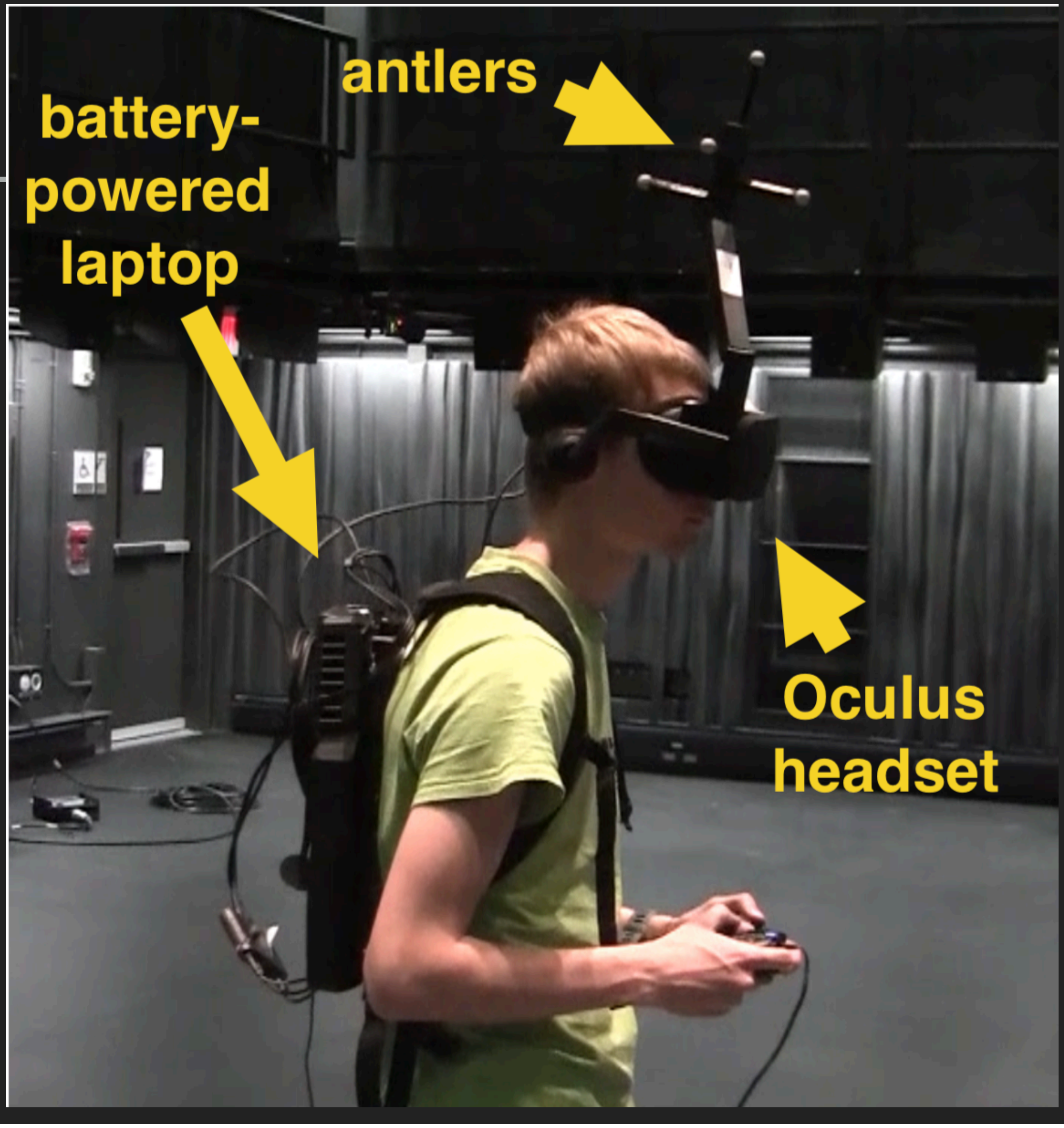
- ATLAS rift is a VR application
- Has very realistic view of the detector
  - Detector geometry converted from .IA files
  - Engineering structures from CATIA
- But can also show simple physics data (jets, tracks etc)
  - Event data delivery by
    - Google datastore - scalable, fast, API hand-made (Google Application Engine), but not free
    - Elasticsearch - scalable, fast, nice API, search/filter functionality. Full/partial event data indexing/delivery demonstrated
- Built on Unreal Engine, so Multiplatform and easy to install



BELLE II

See more in the very nice talk at Joint WLCG / HSF viz workshop

- Written in Unity
- Similarly has very detailed model (identical to GEANT4)
  - Use VRML / FBX
- Event data
  - Human readable
  - Excel csv
  - One per event



SUMMARY

THE PRESENT

- Most experiments have multiple event displays serving various different purposes, and written in with different languages
  - Java, Javascript, Fortran, C++, etc
- and libraries
  - Qt, ROOT, Coin3D, Unreal, Swing, etc
- And use a variety of data formats
  - XML, JSON, ROOT, ……….

THE FUTURE?

- **Social**: Efforts to band together to share experiences, for example:
  - The HEP software foundation has a visualisation group (white paper)
  - Efforts now to create common data formats, common tools
  - Won't replace dedicated event displays, but might reduce code duplication
- **Technical**:
  - *True* 3D through wider use of AR and VR
  - Increased use of browser-based event displays
  - It is currently **VERY** hard to automate the production of good event display pictures (what to show and hide, best view) - can this be improved?

Fin

A data-oriented projection: the "V-Plot"