GUEST CASE STUDY 6:
PARTICLE COLLISIONS

Here's an account from another colleague, Jesse Thaler. As he writes, "I am a theoretical particle physicist, which means that I smash together particles … in my mind."

He is also a rarity — a brilliant physicist at MIT who is also keenly aware of the power of visual communication and works hard at those challenges. Try following his process even if you are not a particle physicist. His thinking is fascinating, and I am grateful that he took the time to write for this book.

One of the challenges in visualizing data in particle physics is that any individual collision has relatively little information, and the science is better captured by histograms that involve many collisions stacked together. Here is a histogram that was involved in discovering the Higgs boson at the Large Hadron Collider (LHC) at CERN in 2012. **8.6.1**

While histograms are the primary data representation we use in particle physics, it is often helpful to visualize one collision event in order to get a sense of the processes at play. To do so, we need to cherry pick a single event that highlights the physics we want to show, while also being visually interesting. Here is one event display from CMS that contains a candidate Higgs boson. **8.6.2**

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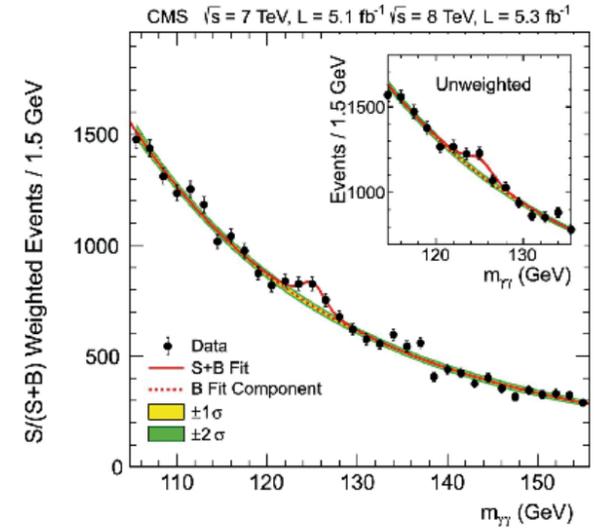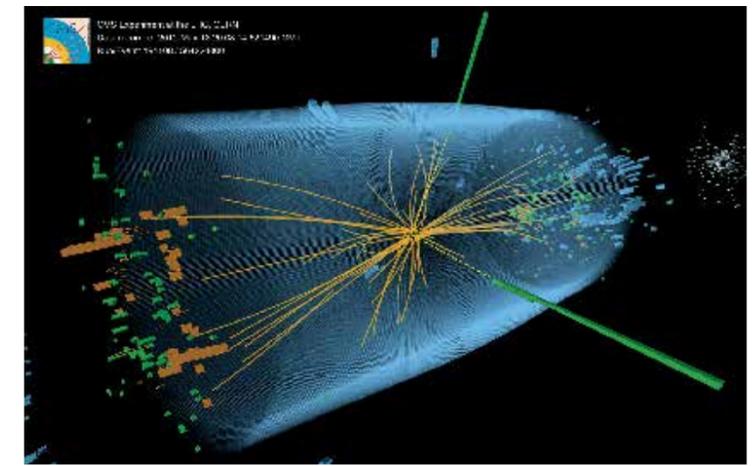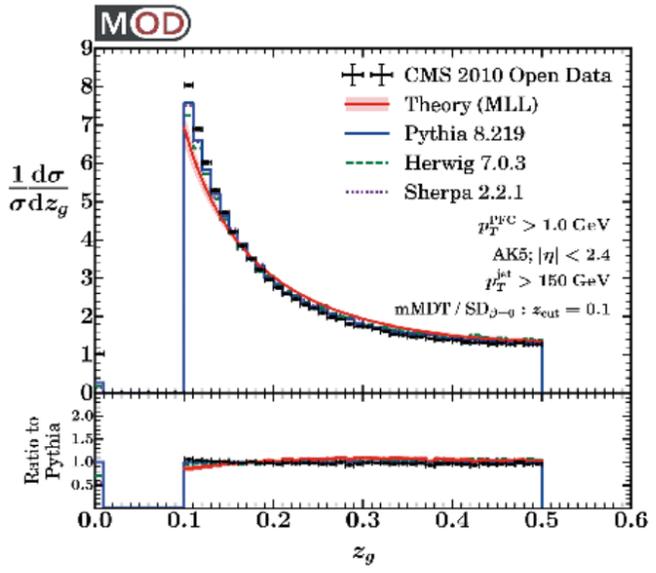
Recently, I had the opportunity to work directly with data from the LHC through the CMS Open Data project. This is the first time in the history of particle physics that data from a collider experiment was made public for use outside of the official experimental collaborations. So while I am a theoretical physicist, my collaborators and I had the unique experience of working directly with experimental data. Not surprisingly, the primary outcome of this research was ... a histogram. **8.6.3**

Or, more accurately, seventy histograms split across two papers.

Because of the historic nature of the CMS Open Data release, and because our work was the very first analysis based on it, our paper was flagged as an "Editors' Suggestion" by *Physical Review Letters* (PRL). As such, we needed to provide an image to use on the PRL website to communicate our work. A histogram simply wasn't going to have the visual impact we wanted. What we needed was an event display.

Where to start? First, I knew that it had to be simple. Some event displays contain multiple views of the same collision along with extra explanatory information, but that would not work for a (relatively small) image on a website. So I definitely wanted to avoid having an event display with multiple panels and extensive text, as in this ATLAS depiction. **8.6.4**

Second, I had to decide on whether to make the event display two dimensional or three dimensional. Collisions happen in 3D, and some of the coolest event displays use 3D representations. **8.6.5**

But I had very little time and no experience using 3D software, so I settled on using a 2D visualization where the colliding beams are perpendicular to the plane of the image and the collision debris sprays out over the page in projection. Here is an example of a CMS event display in this 2D style. **8.6.6**

Since I did not have access to the CMS software to make event displays, I wrote my own simple event display tool using Mathematica. I asked one of my collaborators to get me the information for the most extreme collision event in our sample, and it turned out to be a complete dud visually. **8.6.7**

But you can already see the style I chose: white background, red lines representing the trajectories of (charged) particles, gray radial bars representing the energies of (charged and neutral) particles, and just a thin black circle to hint at the CMS detector.

In any case, I needed an event with more pop. I tried six more events, randomly selected from our sample, but none of them had the pizzaz I wanted.
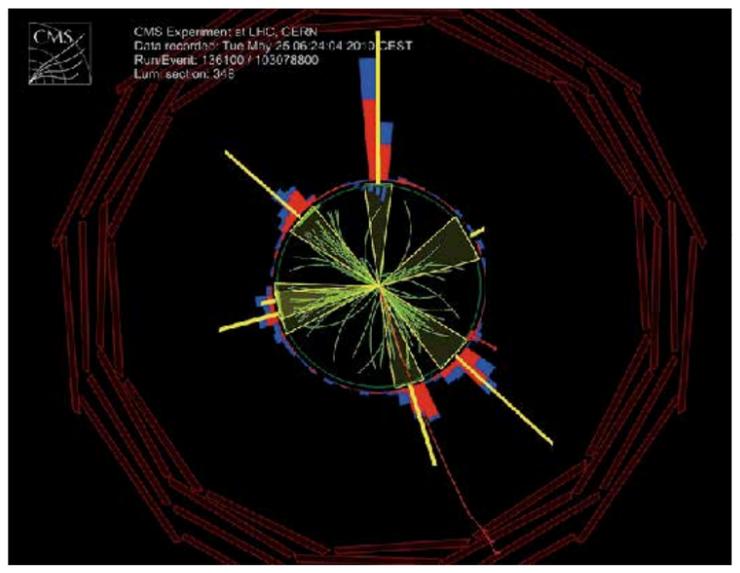
Then, on the next event I tried, I hit the jackpot. I slapped our "MIT Open Data" logo on it, turned the red and gray into the official MIT colors (Pantone 201 and Pantone 423) and sent it off to my collaborators for their approval. **8.6.8**
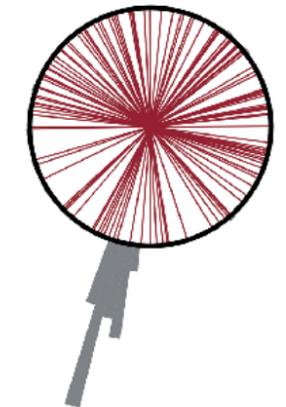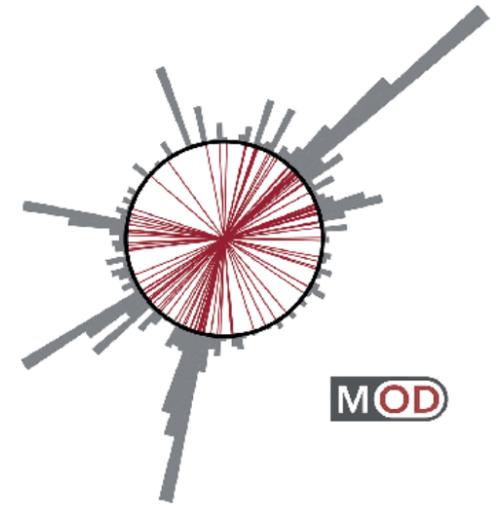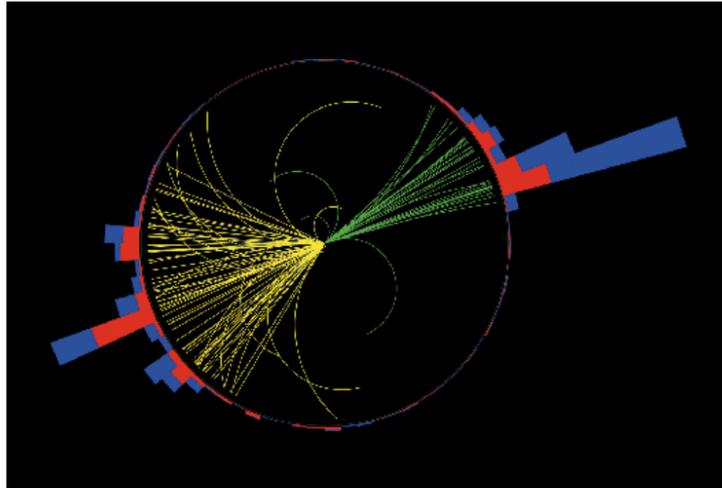

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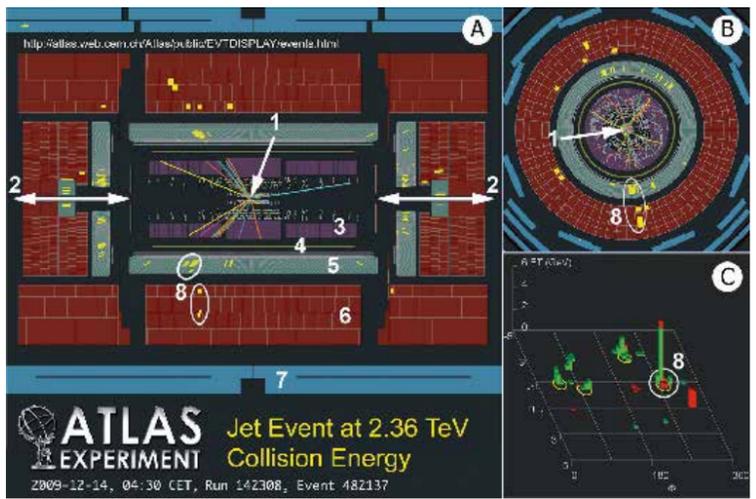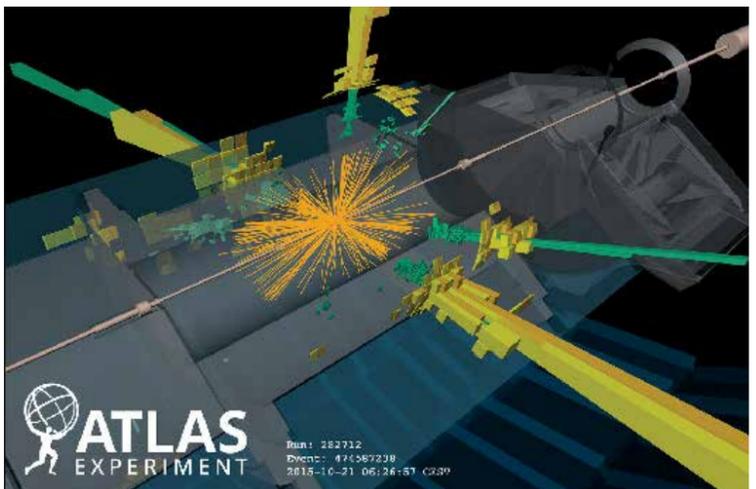
The next day, though, I realized that the event I had selected was not really showing the physics in our paper. This event consisted of five "jets" of collimated particles. But our study was not about multijet events; rather, our study was about the internal structure of a single jet. So no matter how interesting this event display was, it was not capturing the actual science.

In pondering my dilemma, I was reminded of this elegant event display from CMS, which shows a pair of jets, each with three-prong substructure. **8.6.9**

You can see the similarities to my visualization, though I made a number of simplifications. Instead of using two colors (blue and red) to represent the energy deposits, I used just one color (gray) since I thought the distinction would be distracting. Instead of using curved particle trajectories (which is more accurate from the experimental perspective), I straightened the trajectories (which is more accurate from the theoretical perspective).

But what jumped out at me from this CMS display was that, because it uses two different colors for the particle trajectories (yellow and green), the viewer immediately sees that there are two jets. What the viewer does not immediately see, however, is that each jet consists of three subjets, but that could easily be fixed just by color coding the subjets of interest.

Here is the single jet of interest from my five-jet event, with its subjets highlighted in green and blue. **8.6.10**

I kept the particle trajectories within the jet, but made them dark gray to draw attention away from them. So now I had the correct physics, but it seemed strange to have a jet floating on the page without any context. I therefore decided to summarize the four other jets in the event as simple gray arcs, which restored some balance to the event display. **8.6.11**

Jet aficionados might be interested to know that the opening angles of the arcs match the clustered jet size (overlapping since this is really happening in 3D) and the areas of the arcs are proportional to the jet energies.
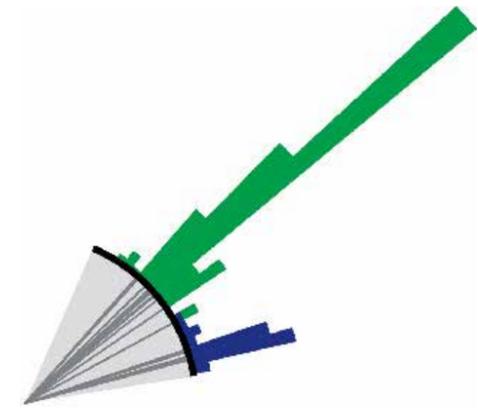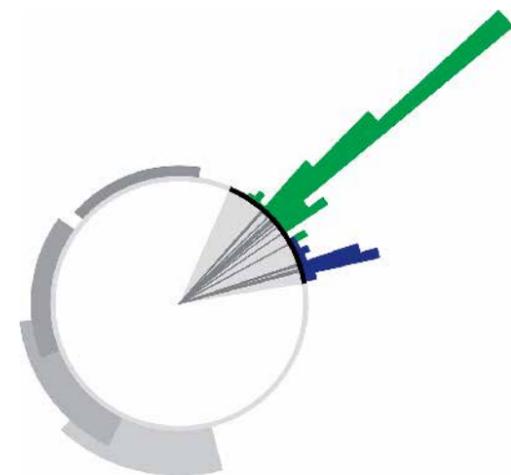
This last image captures the physics better than I could have ever hoped. The event is really happening in 3D, but I got lucky that the green and blue subjets can still be seen clearly in this 2D projection. Moreover, the fact that the blue subjet has significantly less energy than the green one is actually a key finding of our study, shown scientifically in the above histogram but captured viscerally in a single event display.

So now I had two event displays. One of a dynamic collision event with five jets, four of which were irrelevant to the science. One with a single jet isolated to show its two-prong substructure, but lacking a bit in visual interest. What to do? Use them both, of course, with a rightward arrow to indicate that by processing the left image, one could arrive at the right one. [See opening image of this case study.]

My collaborators approved wholeheartedly.

There is one last feature that I should point out. These jets arise from the dynamics of the strong force, otherwise known as quantum chromodynamics. Here, "chromo" does not refer to actual color, but to a mathematical structure involving three labels, typically given as "red," "green," and "blue." So yes, I admit that my color scheme involves a gratuitous visual pun, but hopefully that is the only gratuitous feature of the final image.

In the next five case studies, we'll be looking at examples of how I photographed objects *as they are*, without the need to create an explanatory metaphor. There's a hidden agenda here. The best thing I can accomplish in these pages is to encourage you to look at your work in new ways and to learn to see the world from new points of view. You'll see in this first case study how small changes result in different perspectives.