Physics 3306

Provides an introduction to a wide variety of topics in classical (pre-quantum) physics as a bridge to prepare students for subsequent upper-level courses in physics. The topics covered include thermodynamics, fluid mechanics, mechanical waves, optics, radiation, electromagnetic phenomena, atoms, and laboratory techniques. Prerequisites: C- or better in PHYS 1106; and in PHYS 1304 or PHYS 1308.

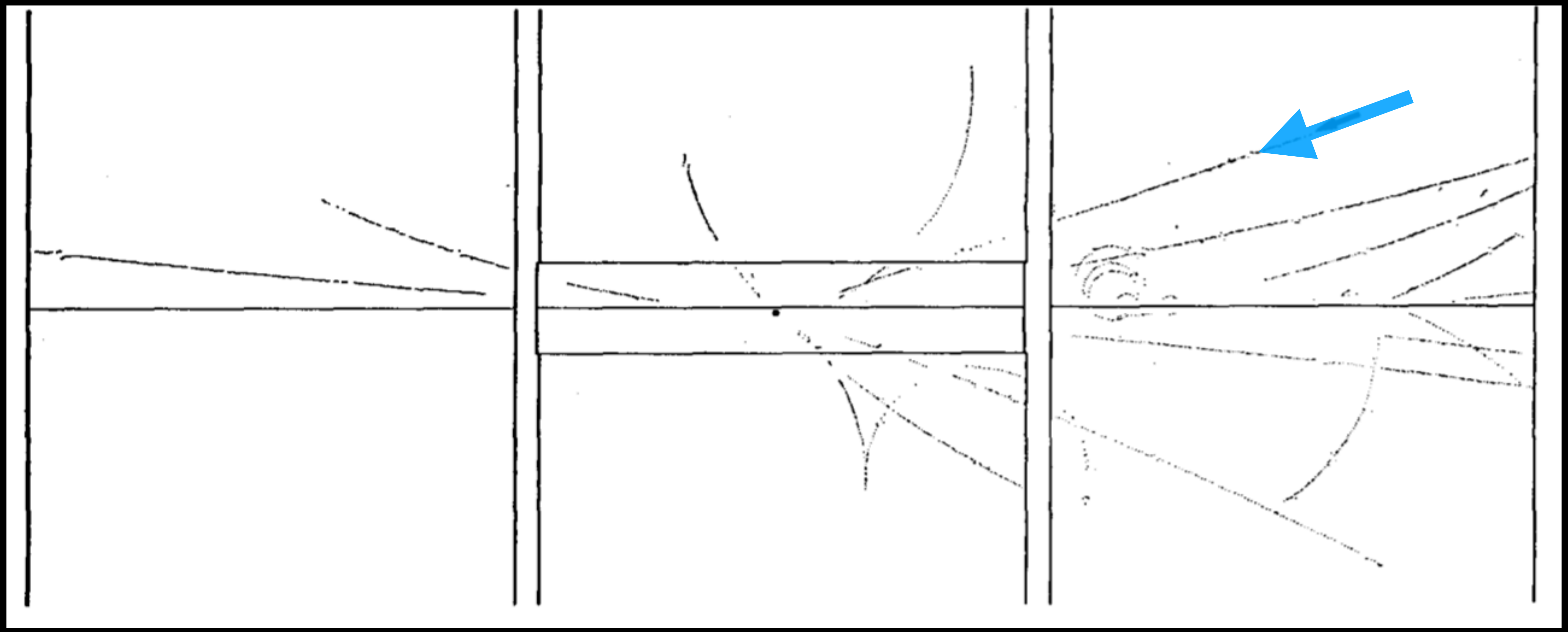
Saptaparna Bhattacharya

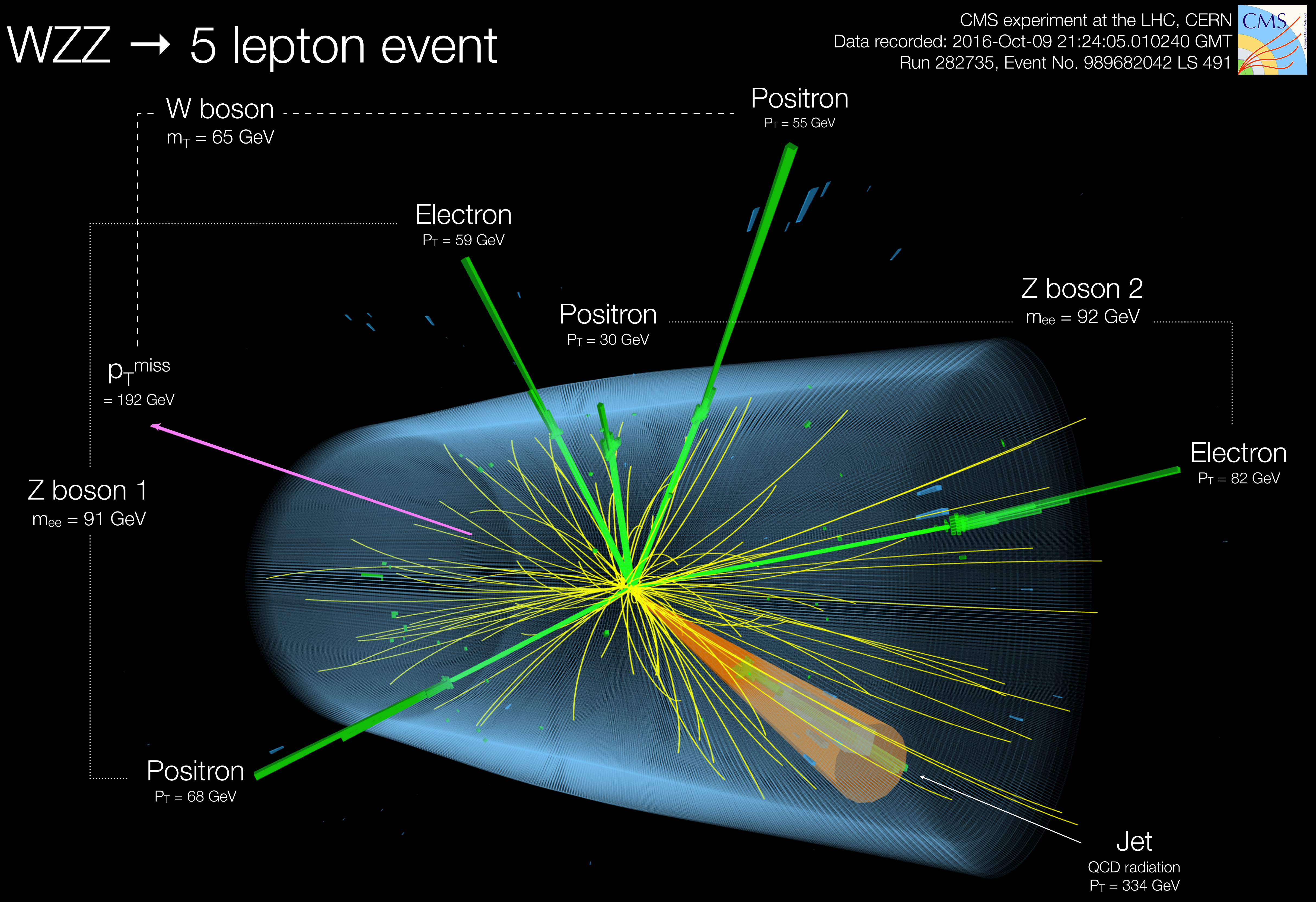
January 29th, 2025

Undergraduate research

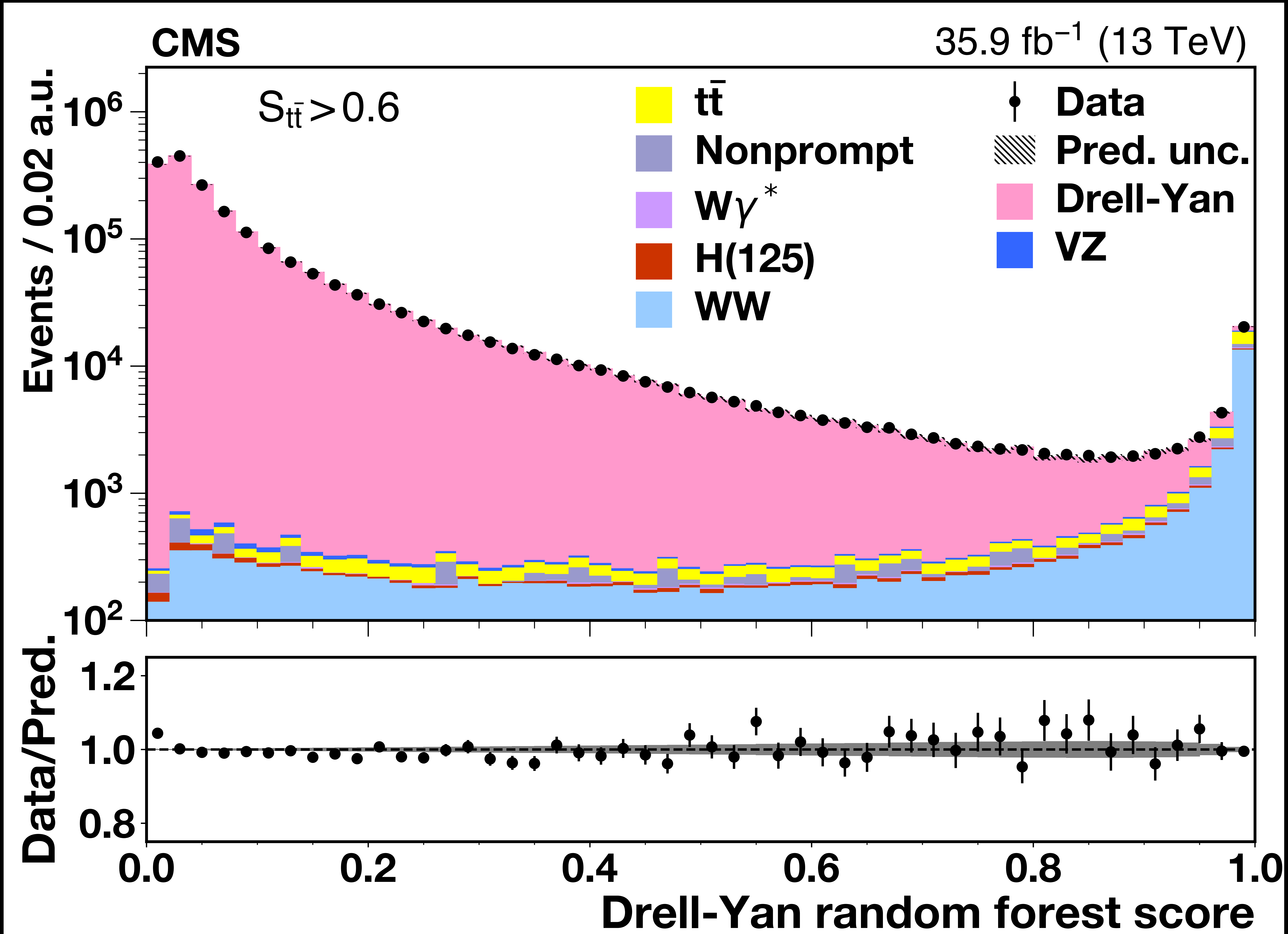
- Some of you expressed interest in doing research with me
- I found that the department supports undergraduate research
- We could come up with a project
- For ML enthusiasts, please look into downloading scikit learn
- Research with me as no bearing on course performance!
- We could start our kick-off meeting on Monday, Feb 3rd

I study very rare events

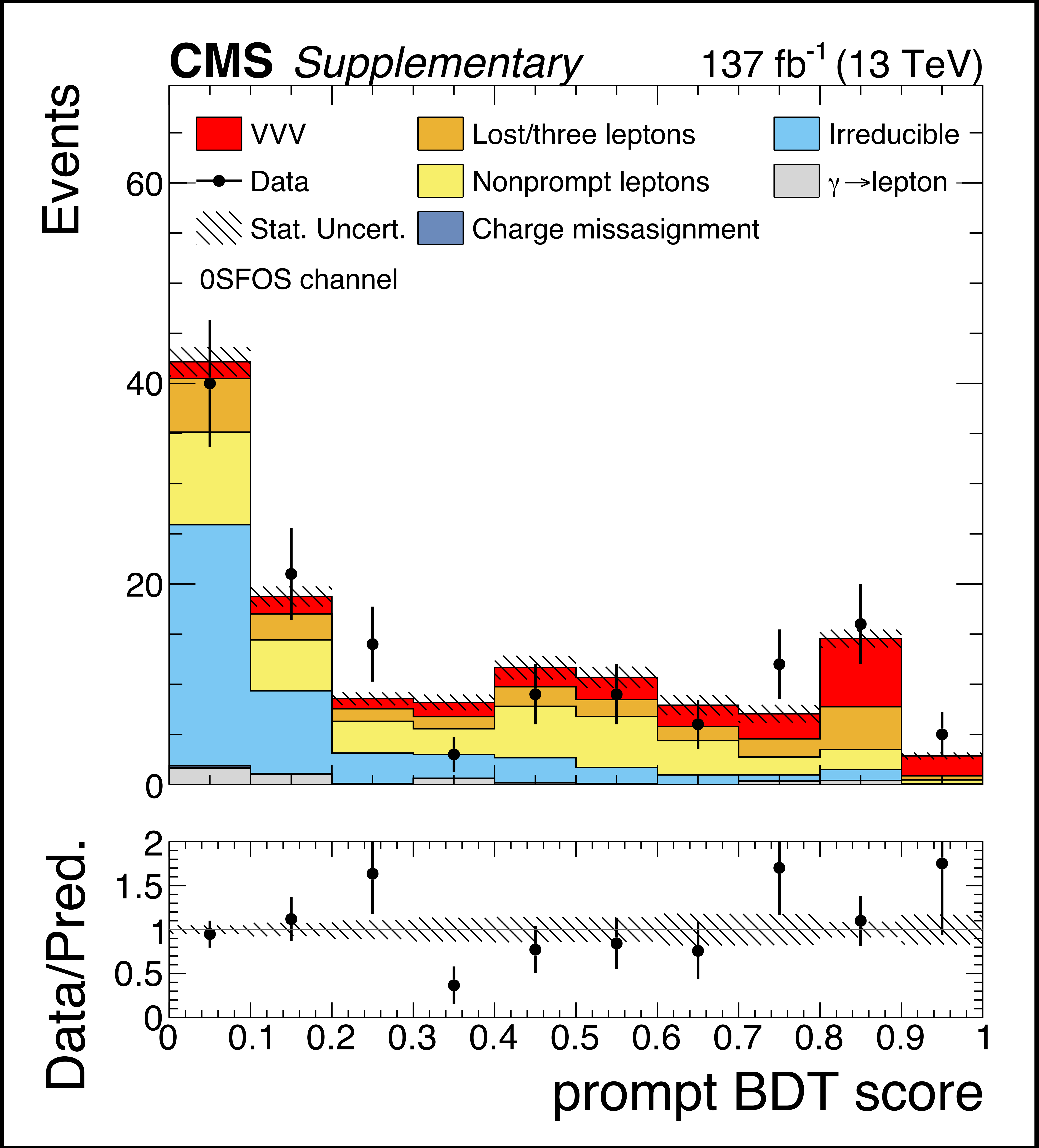




Has anyone seen graphs like this?

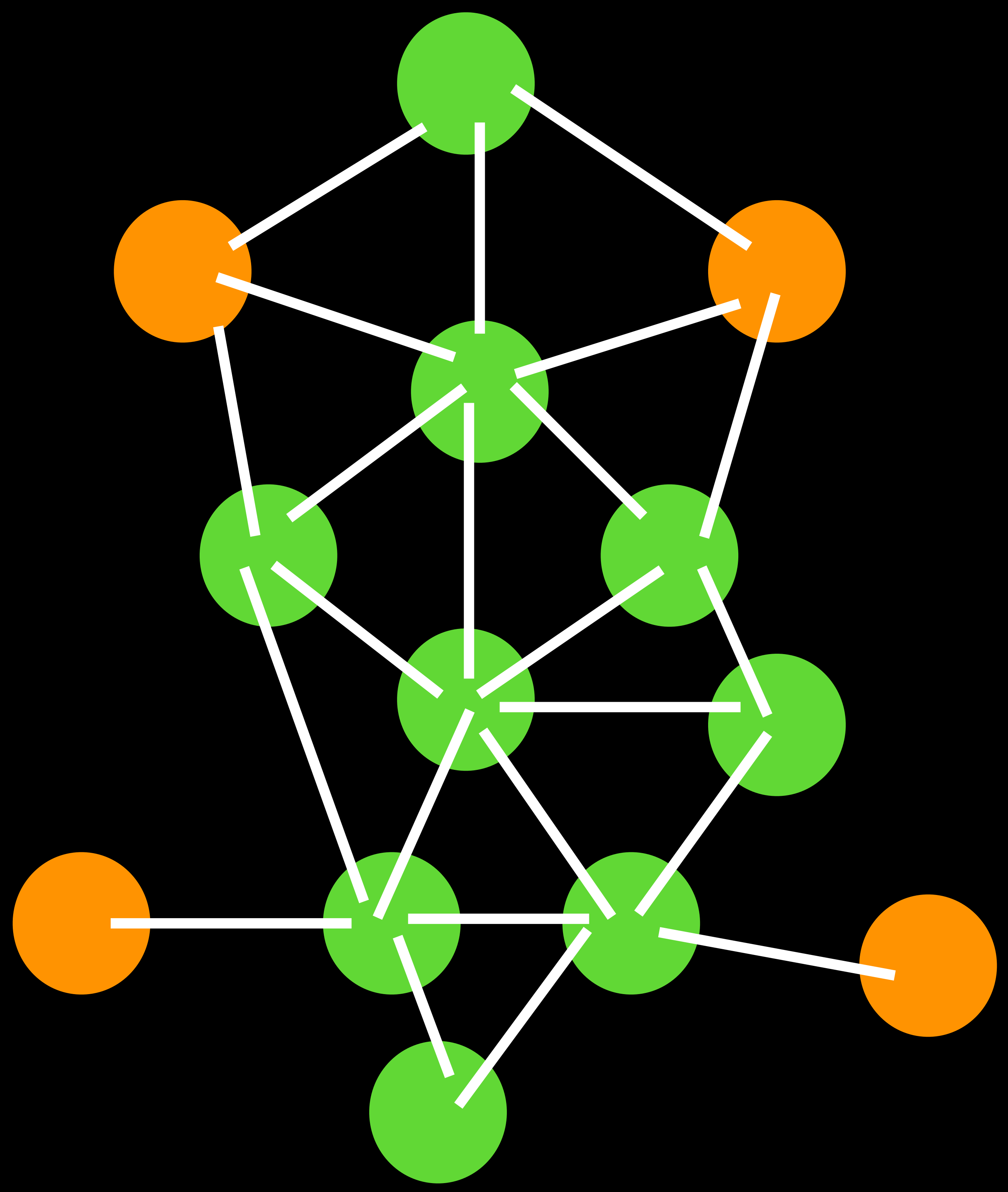


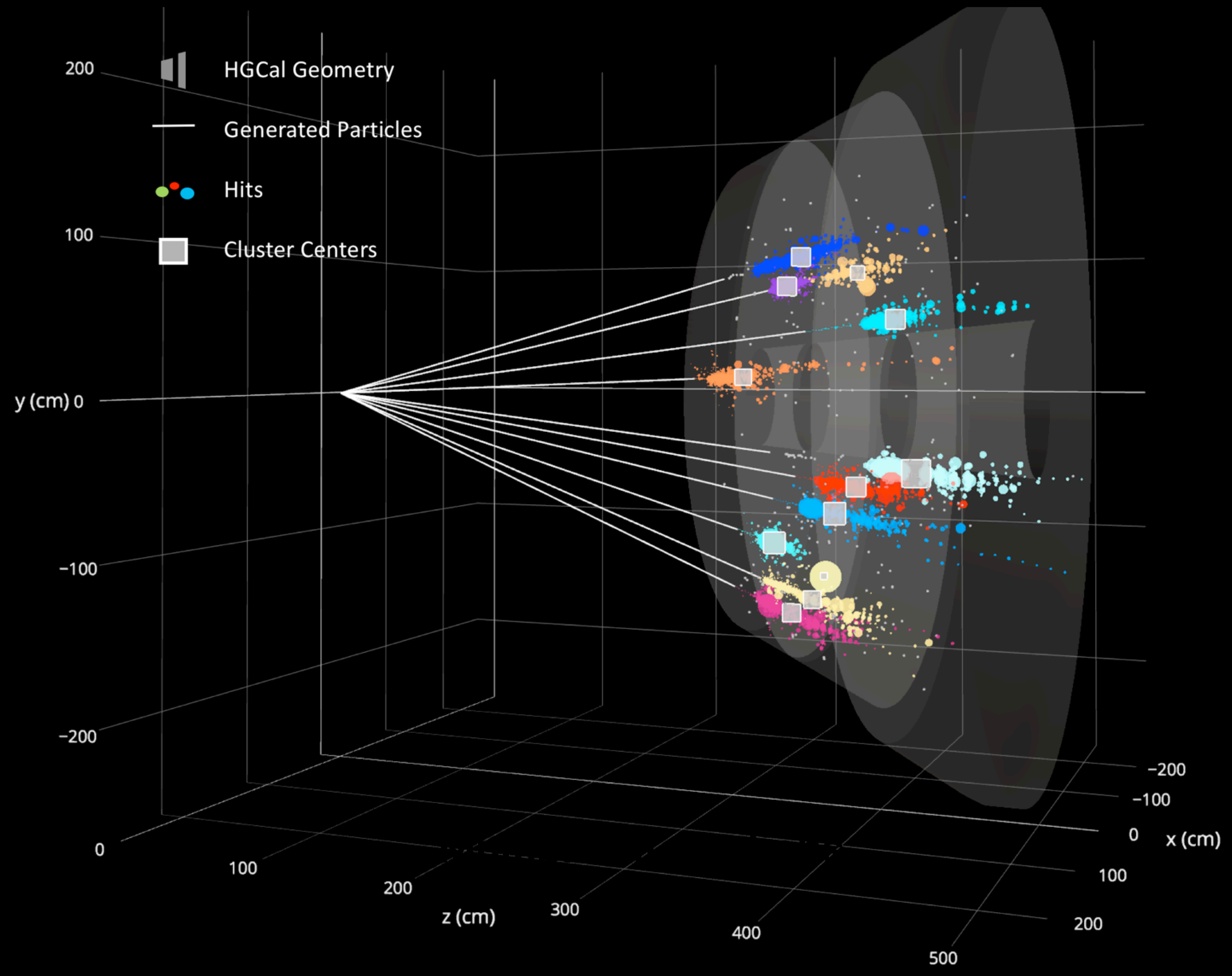
For my analyses, no clear separation between signal and background



Using Machine Learning to harness the power of new detectors

Calculate features of edges and designate as signal or noise

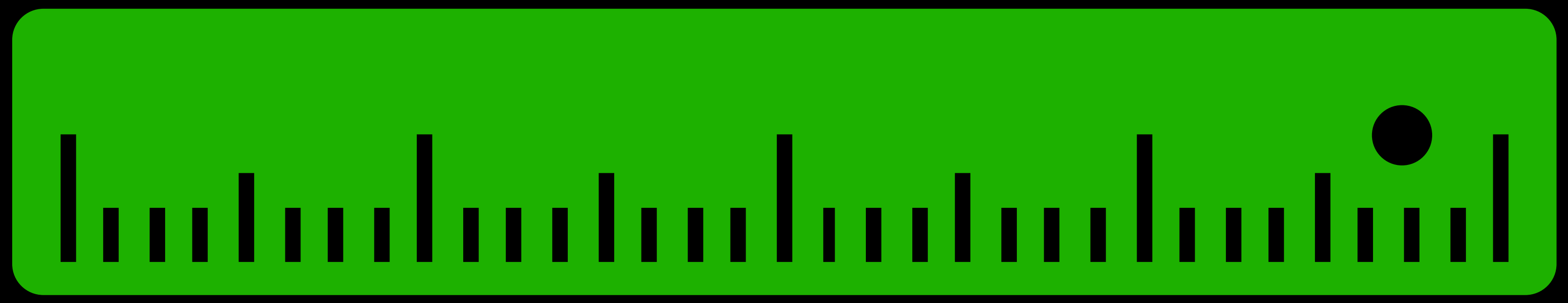




Recap

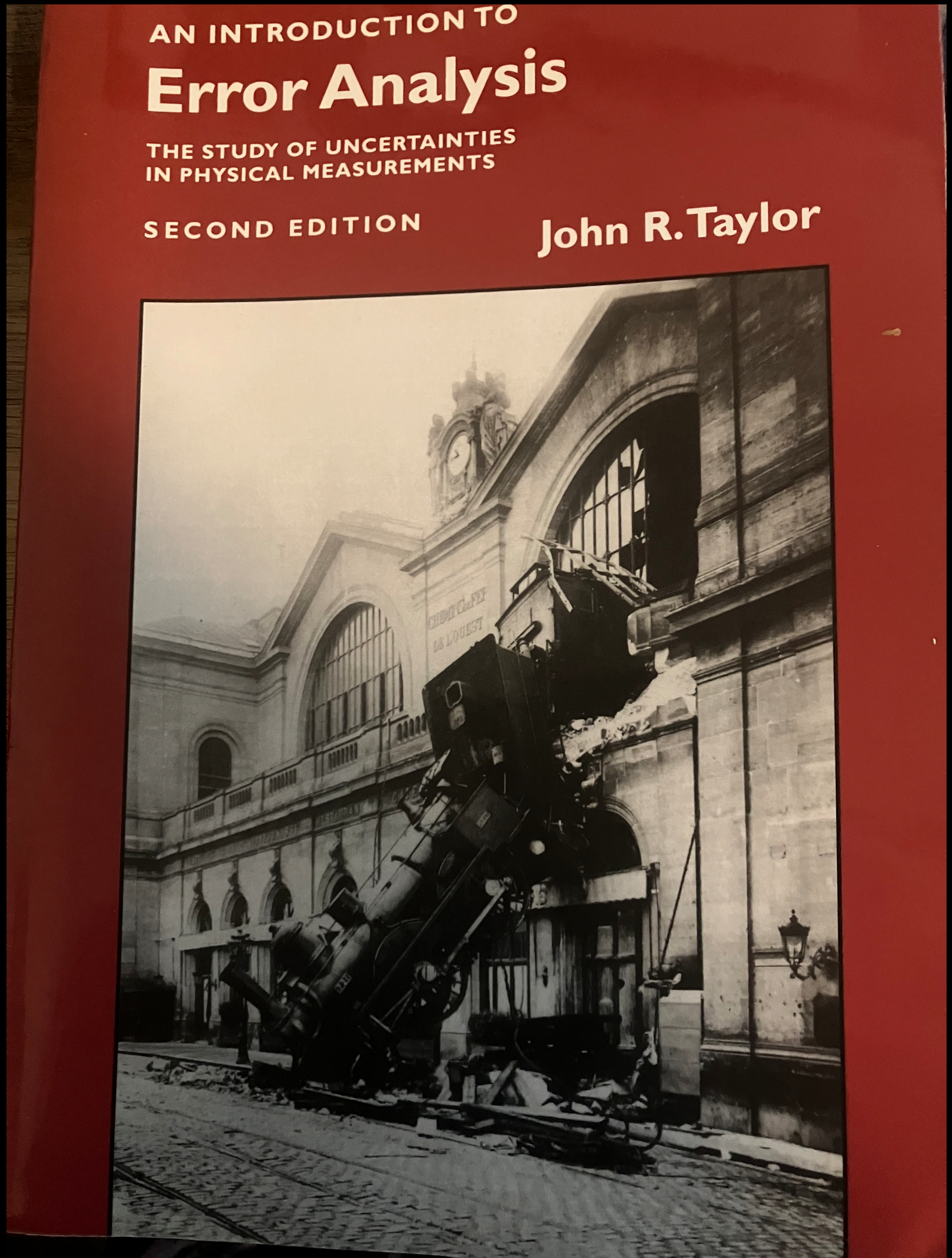
Structure of the lab

- Any measurement, whether it is a measurement with a ruler or measurement with a measuring scale, is always accompanied with an error!
- Error analysis “is the study and evaluation of these uncertainties”
- It serves two main functions:
    - Allows us to estimate uncertainty
    - Reduce them when necessary

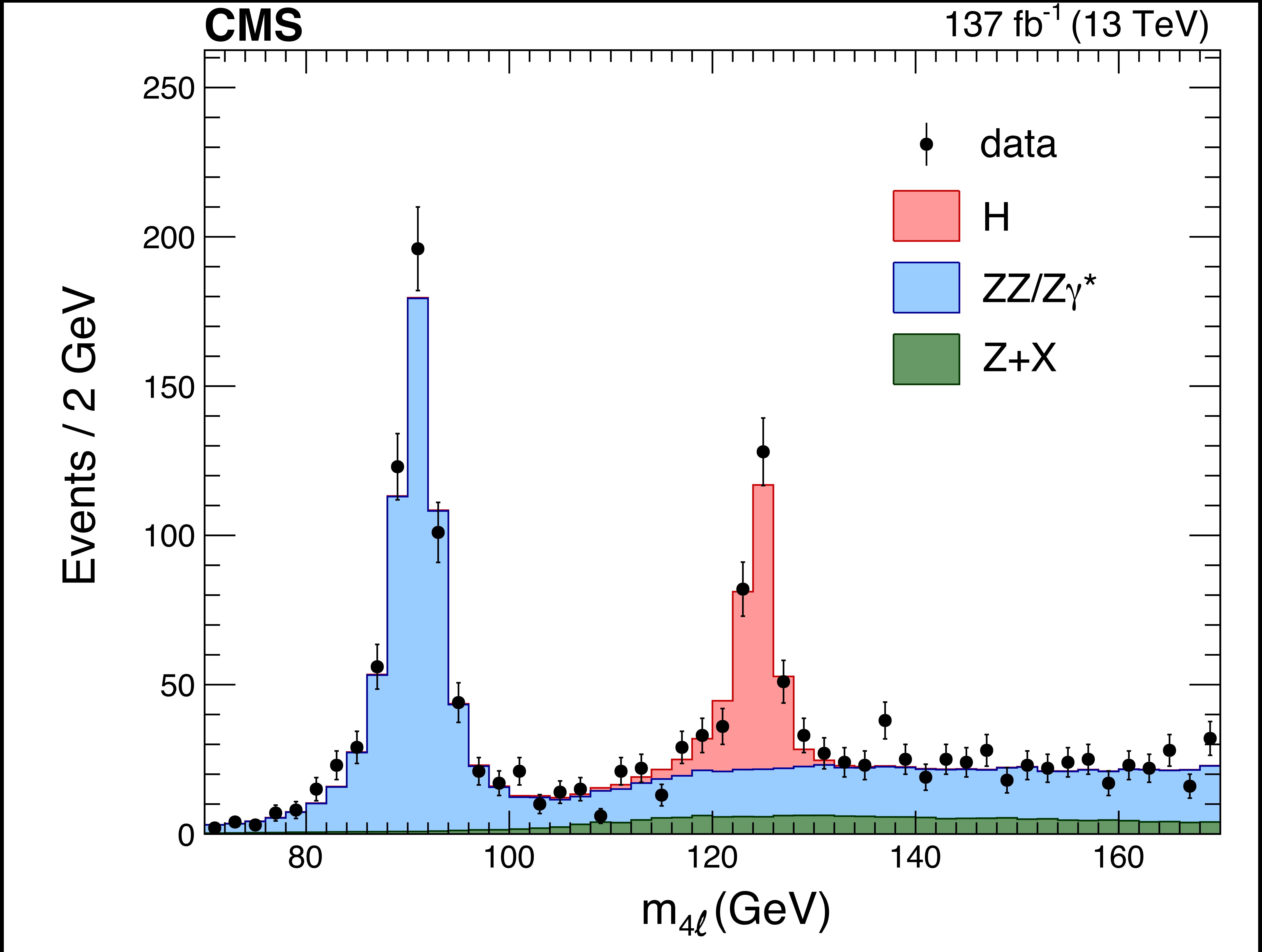


Reference

Considered a classic!



Let's take a quick detour: what makes a good graph?



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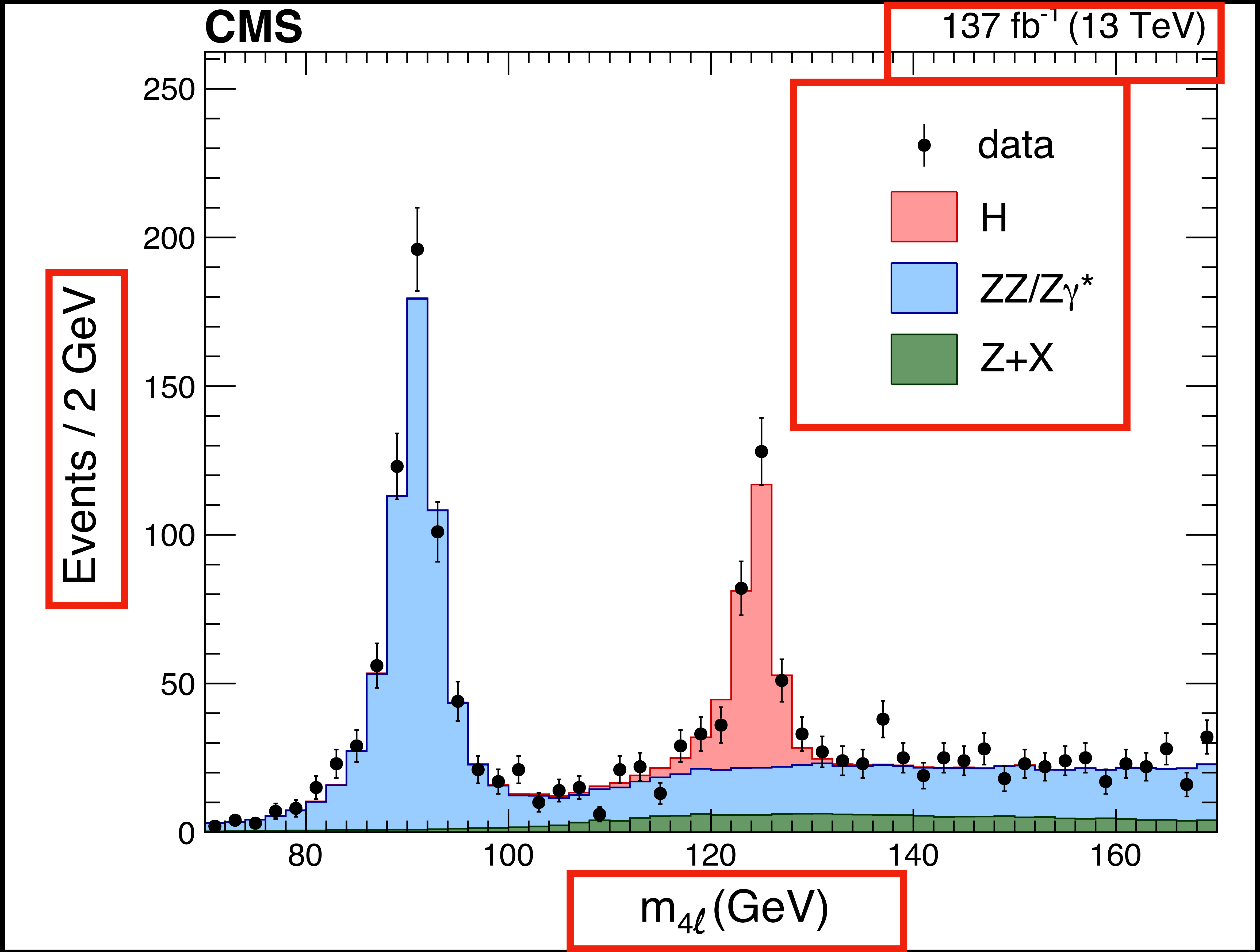
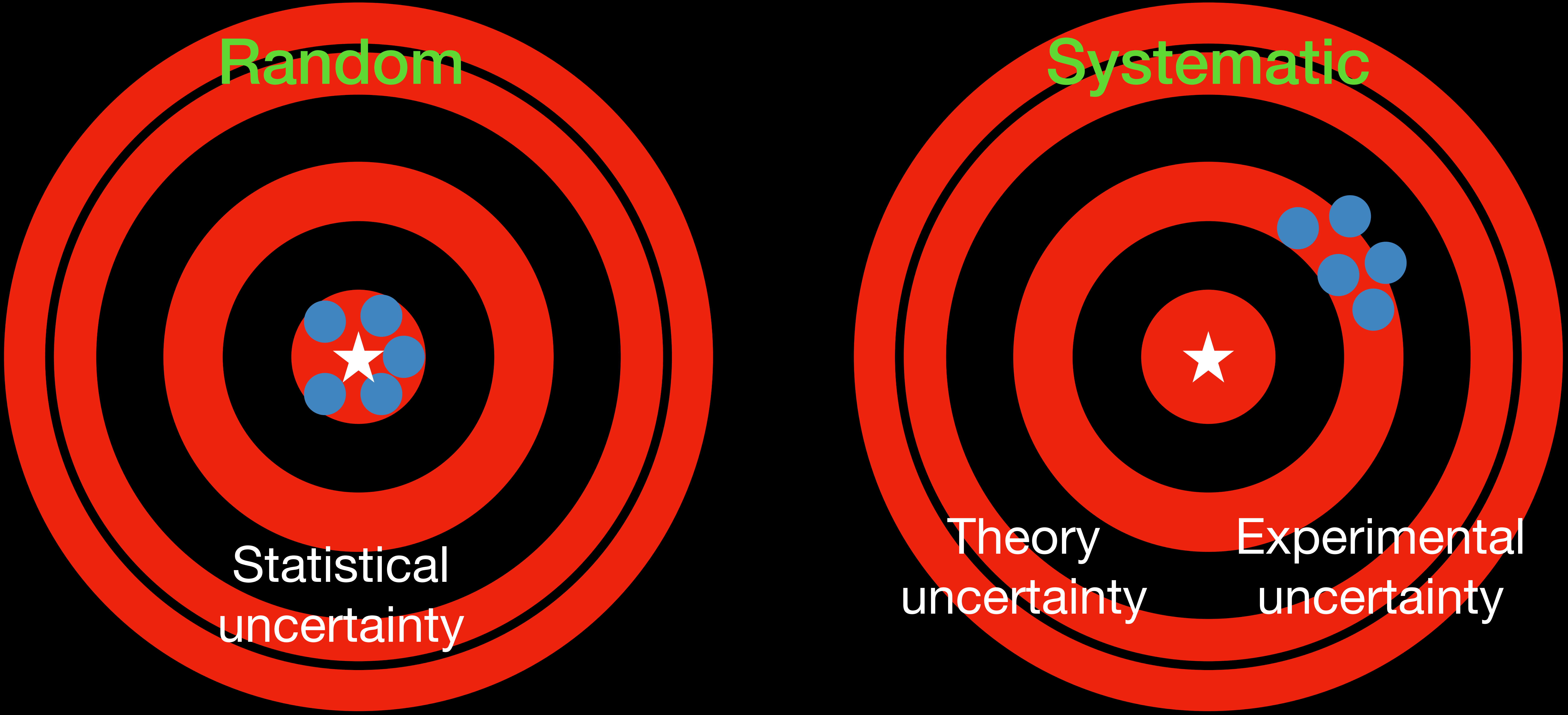


- What do you notice?
  - What kind of graph is this?
  - Clear axis labels!
  - Legends clearly marked
  - Data-taking conditions clear
  - Placement of x-axis ticks adjusted to the variable being plotted
  - Can you read the location of the read peak?

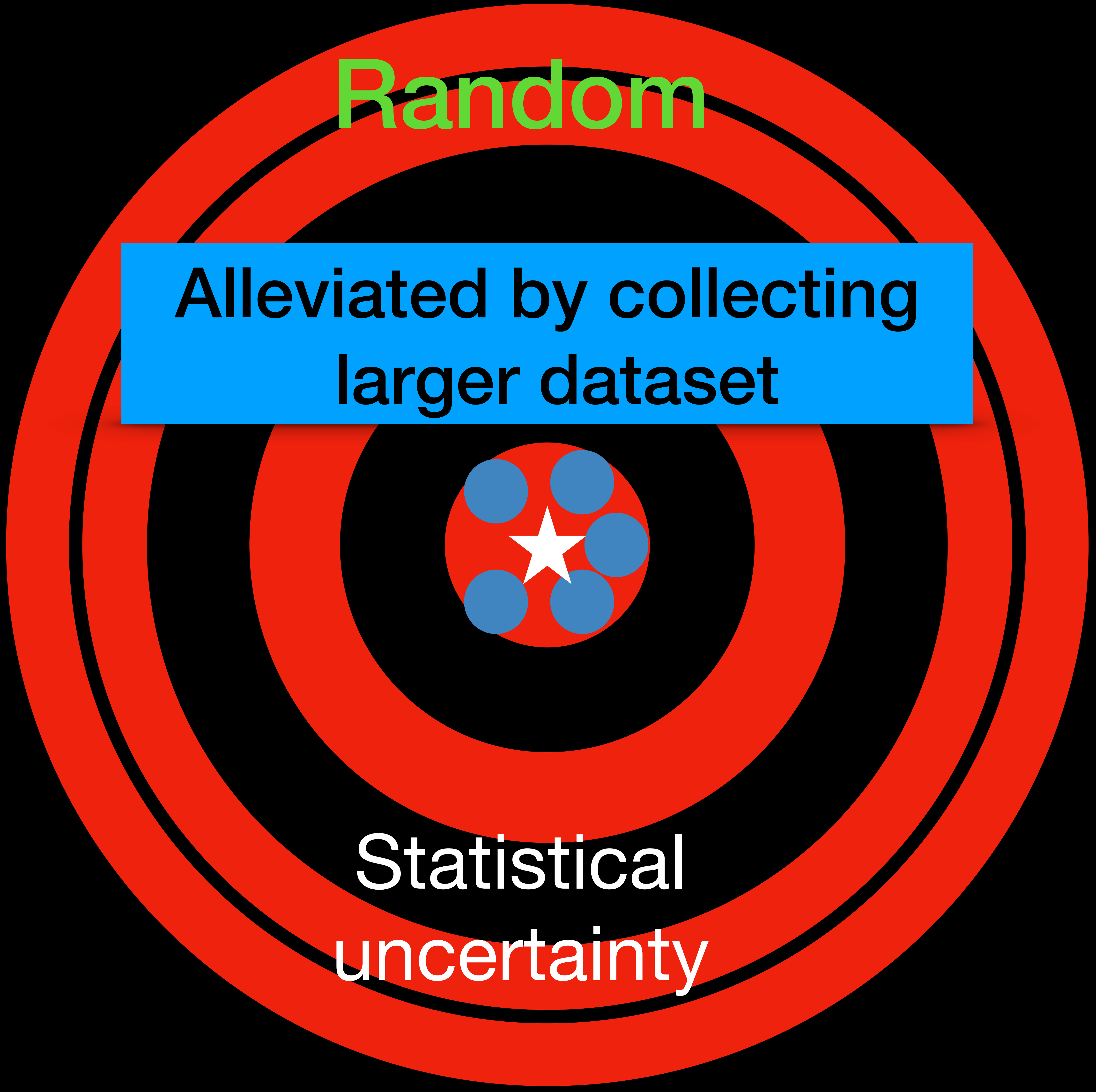
Types of uncertainties

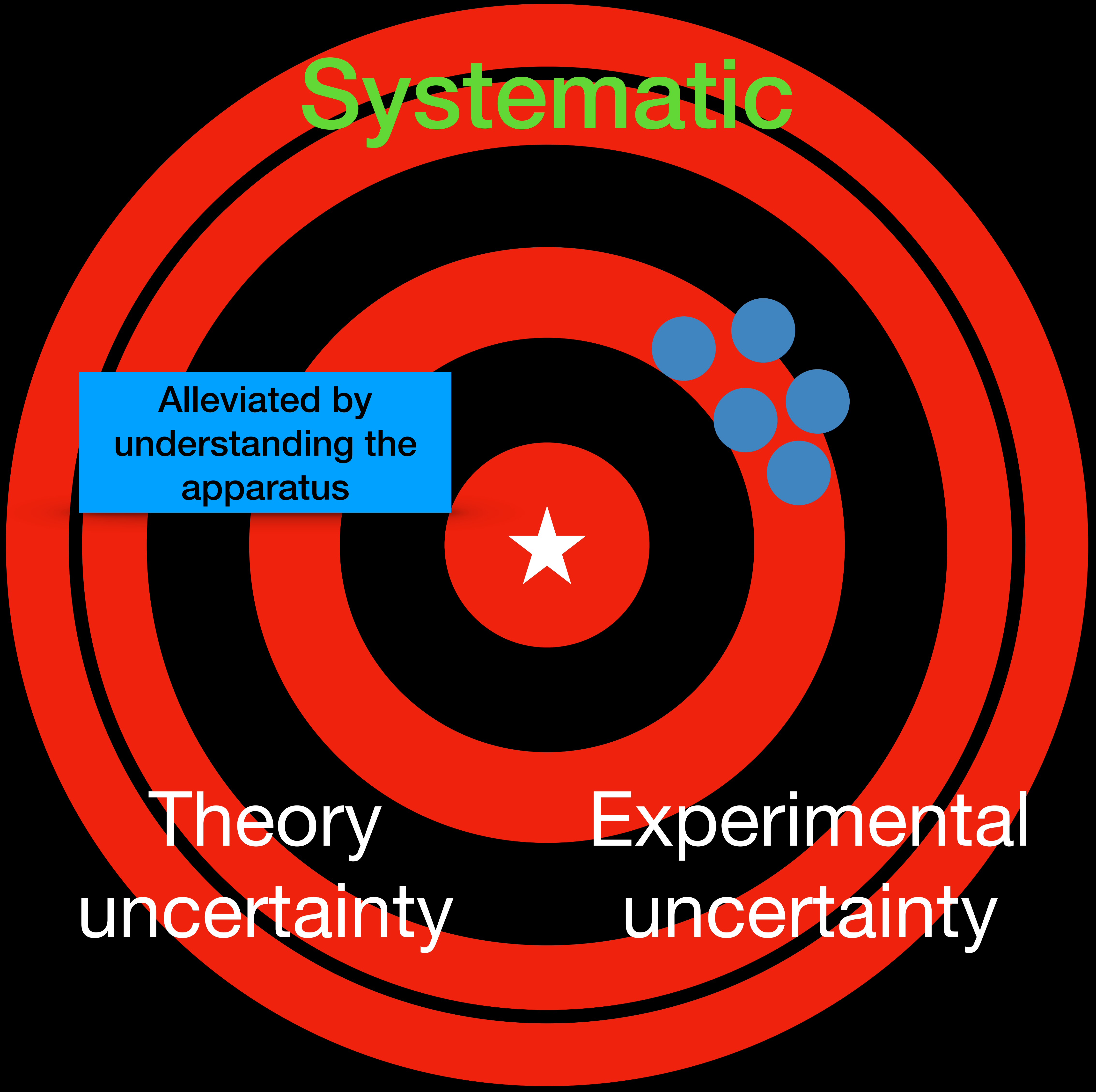


Sources of systematic uncertainty

- Can you name some sources of systematic uncertainty?
- Think of any measurement
  - Measuring length or
  - Measuring mass

Types of uncertainties



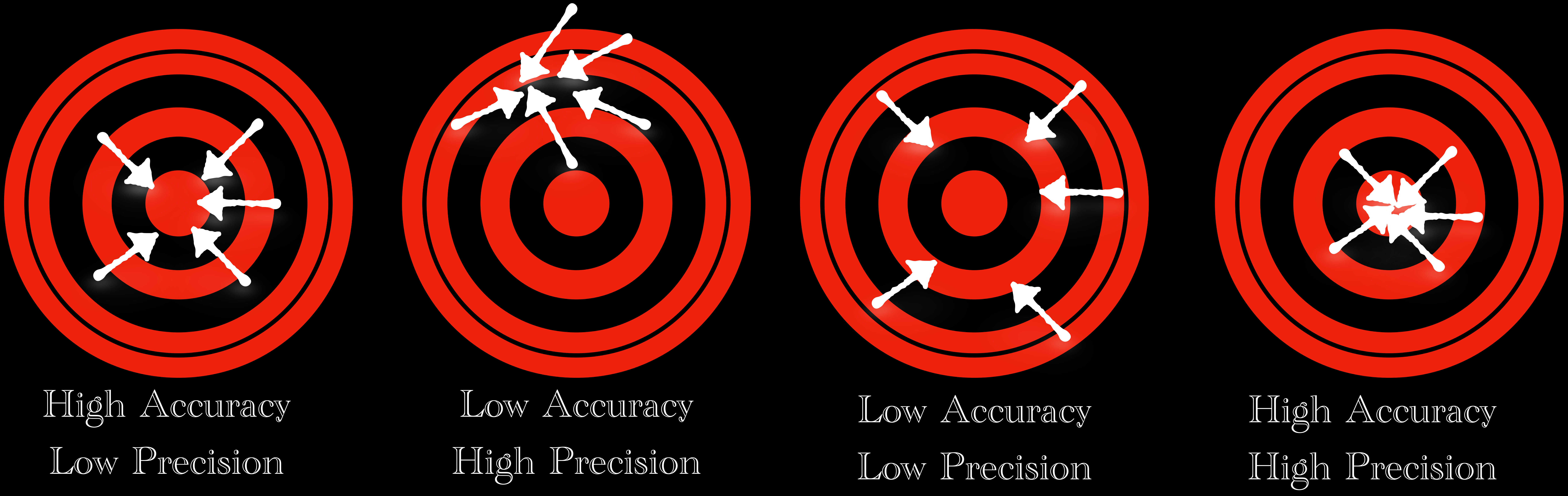


Types of uncertainties

- Which is the bigger problem?
    - Random (statistical uncertainty) or systematic uncertainty

Precision and accuracy

- Terms often used interchangeably in English!
- Not in this lab though!

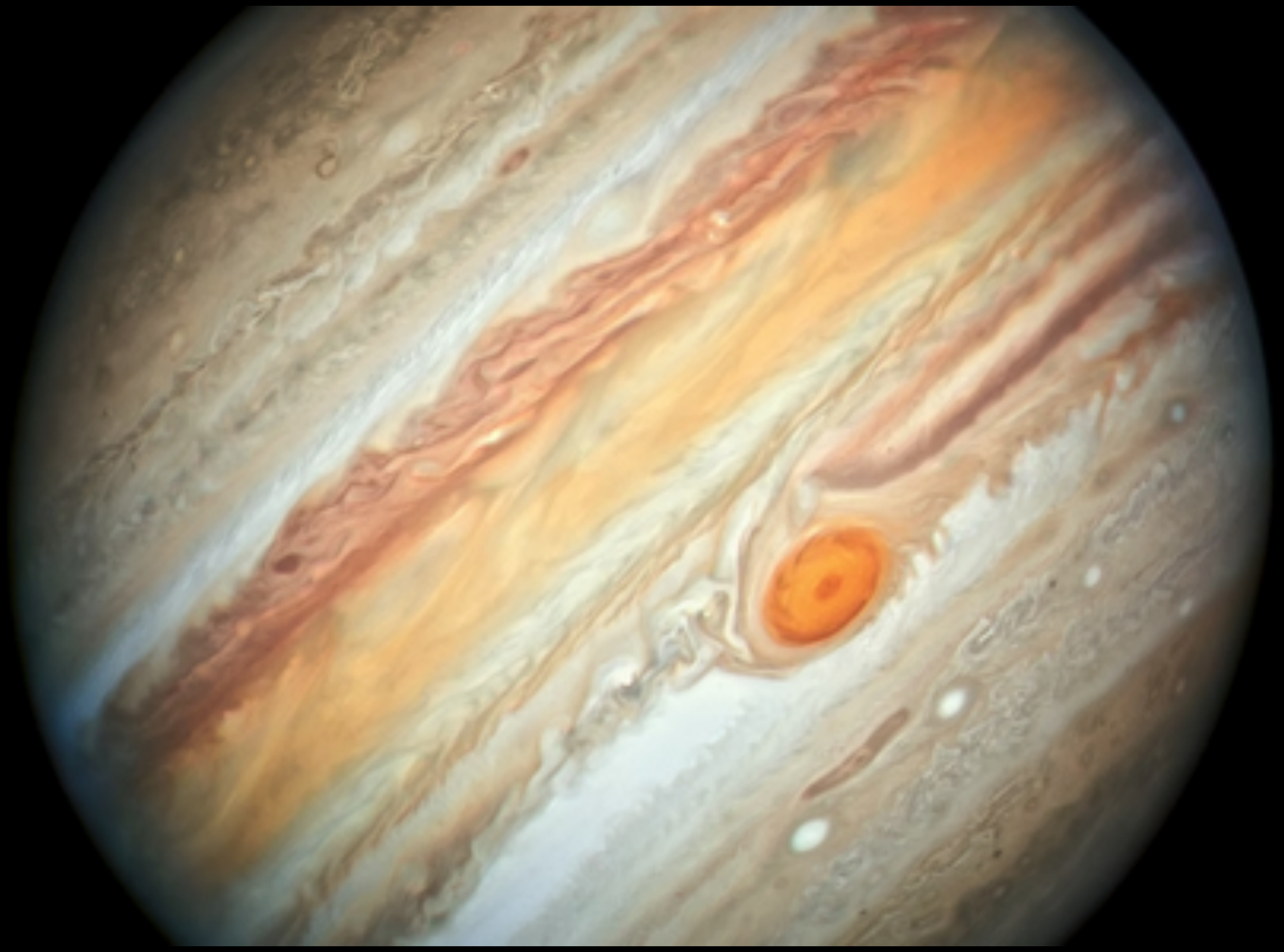


Reducing statistical uncertainties

- How would you reduce random or statistical uncertainties?

Robert Hooke

- What did he do?



Known for	
	Balance spring
	Conical pendulum
	Constant force escapement
	Cymatics
	Discovery of Gamma Arietis
	Discovery of cell
	Discovery of Great Red Spot
	Hooke's law
	Hooke's joint
	Hooke's instrument
	Hooke's wheel
	Micrographia
	Microscopy
	Portable camera obscura
	Reticle
	Schlieren
	Shadowgraph
	Structural coloration
	Sash window
	Tin can telephone

Discussion from last week (Jan 22nd)

Reducing statistical uncertainties

- Take many measurements and compute an average!
- Say, we are measuring length (ℓ), take many measurements ($\ell_1, \ell_2, \ell_3, \ell_4, \ell_5 \cdots$)
- Take average:
- $\bar{\ell} = \frac{1}{N} \sum_{j=1}^{N} \ell_j$
- This is the best estimate of the true measurement

The standard deviation

- The standard deviation (SD) or σ_ℓ is a measure of the average uncertainty of the individual measurements ℓ_i:
- $$\sigma_\ell = \sqrt{\frac{1}{N-1}\sum_{j=1}^{N}(\ell_j - \bar{\ell})^2}$$
  - Say we have 3 measurements (2.9, 3.0, 3.1 cm), average is 3.0 cms and the Standard deviation is: 0.1 cm
  - The standard deviation associated with a measurement stabilizes after several measurements are taken
  - When the value stabilizes, we know that the measurement is more reliable

The standard deviation of the mean

- The standard deviation of the mean (SDOM) can be written as:
    - $\sigma_{\bar{\ell}} = \dfrac{\sigma_\ell}{\sqrt{N}}$, where N is the number of measurements
    - With more measurements, the value of $\sigma_{\bar{\ell}}$ decreases, measurement becomes more precise
    - How much does $\sigma_{\bar{\ell}}$ decrease if N goes from 1 to 4? 1 to 100?

Propagation of uncertainties

- I am measuring the density, which is a function of mass m and volume V and is given by:
  - $\rho(m, V) = m/V$
  - For a functional dependence of one measured quantity x, $f(x)$ with an uncertainty Δx in x, the uncertainty in $f(x)$ can be computed as:
    - $\Delta f_x = |f(x + \Delta x) - f(x)|$
  - For multiple variables, as is the case here, we add the uncertainties in quadrature:
    - $\Delta \rho = \sqrt{(\Delta \rho_m)^2 + (\Delta \rho_v)^2} \equiv \sqrt{|\rho(m + \Delta m, V) - \rho(m, V)|^2 + |\rho(m, V + \Delta V) - \rho(m, V)|^2}$

Significant figures - I

- Significant figures
  - “the digits in a measured number that are considered reliable and contribute to the accuracy of the measurement”
  - If you tell me that the value of a quantity is 4.9, is it 4.99999999….?
  - There are some rules regarding significant figures (http://www.astro.yale.edu/astro120/SigFig.pdf)

Significant figures - II

What is a "significant figure"?

The number of significant figures in a result is simply the number of figures that are known with some degree of reliability. The number 13.2 is said to have 3 significant figures. The number 13.20 is said to have 4 significant figures.

Rules for deciding the number of significant figures in a measured quantity:

(1) All nonzero digits are significant:

1.234 g has 4 significant figures,
1.2 g has 2 significant figures.

(2) Zeroes between nonzero digits are significant:

1002 kg has 4 significant figures,
3.07 mL has 3 significant figures.

(3) Zeroes to the left of the first nonzero digits are not significant; such zeroes merely indicate the position of the decimal point:

0.001^o C has only 1 significant figure,
0.012 g has 2 significant figures.

(4) Zeroes to the right of a decimal point in a number are significant:

0.023 mL has 2 significant figures,
0.200 g has 3 significant figures.

(5) When a number ends in zeroes that are not to the right of a decimal point, the zeroes are not necessarily significant:

190 miles may be 2 or 3 significant figures, 50,600 calories may be 3, 4, or 5 significant figures. The potential ambiguity in the last rule can be avoided by the use of standard exponential, or "scientific," notation. For example, depending on whether 3, 4, or 5 significant figures is correct, we could write 50,6000 calories as:

5.06×10^4 calories (3 significant figures)
5.060×10^4 calories (4 significant figures), or
5.0600×10^4 calories (5 significant figures).

Today’s lab (Jan 29th)

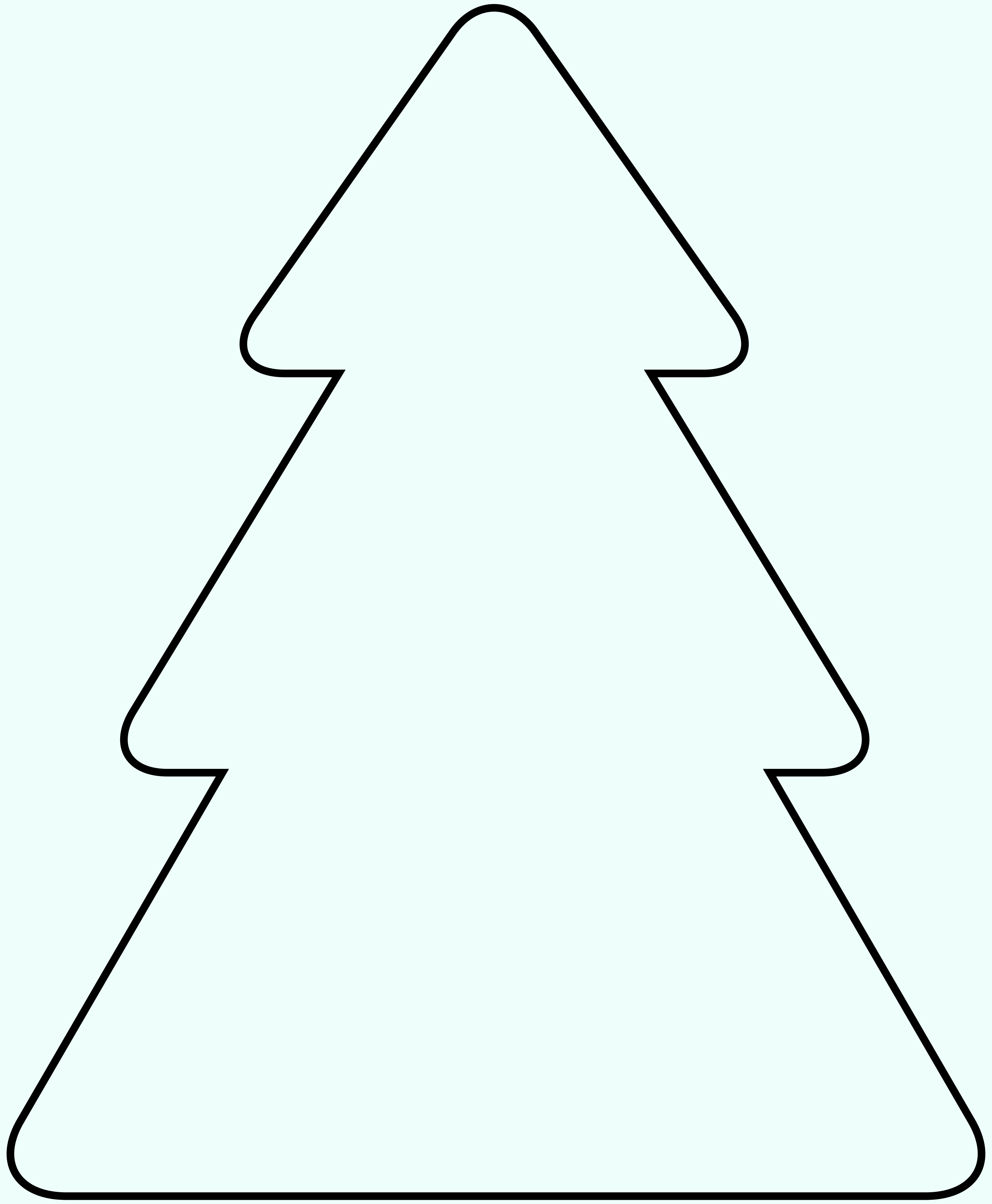
Overarching goal

- Measure length of paper using rulers A, B and C
- Measure mass using scale
- Measure time
- Measuring voltage with a multimeter

Let’s measure some lengths

- Let’s measure the length, breadth and width of the cuboid. Please report lengths, breadths and widths using all three kinds of rulers: A, B and C

Let’s measure the length of a special tree



Let’s measure the mass

- Are we measuring mass or weight?
- What does a digital scale do?

Let’s measure the mass

- A measuring scale, typically a digital scale, works by using a load cell that converts the force applied by an object's weight into an electrical signal, which is then measured and displayed as a weight reading on the scale

Let’s measure the density too

- While you’re at it, go ahead and measure the density and record it in the notebook

Let's measure time!
Or time intervals!

- This ball record the time as it hits the ground
- Use the tape measure to define distance and record the time
- Do this for a few measurements
- What do the values look like?
- Make a graph!

Finally, let's measure a slightly different quantity: voltage

- Take a battery
- Figure out what is its voltage
  - Battery voltage is the difference in electrical potential between a battery's positive and negative terminals
- How do you know that it is correct?