# EIC science with high school students


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Winter Workshop on Nuclear Dynamics
Jackson Hole, Wyoming Feb 11-18 2024

OPINION

SCIENTIFIC AMERICAN

SEPTEMBER 14, 2023 | 4 MIN READ

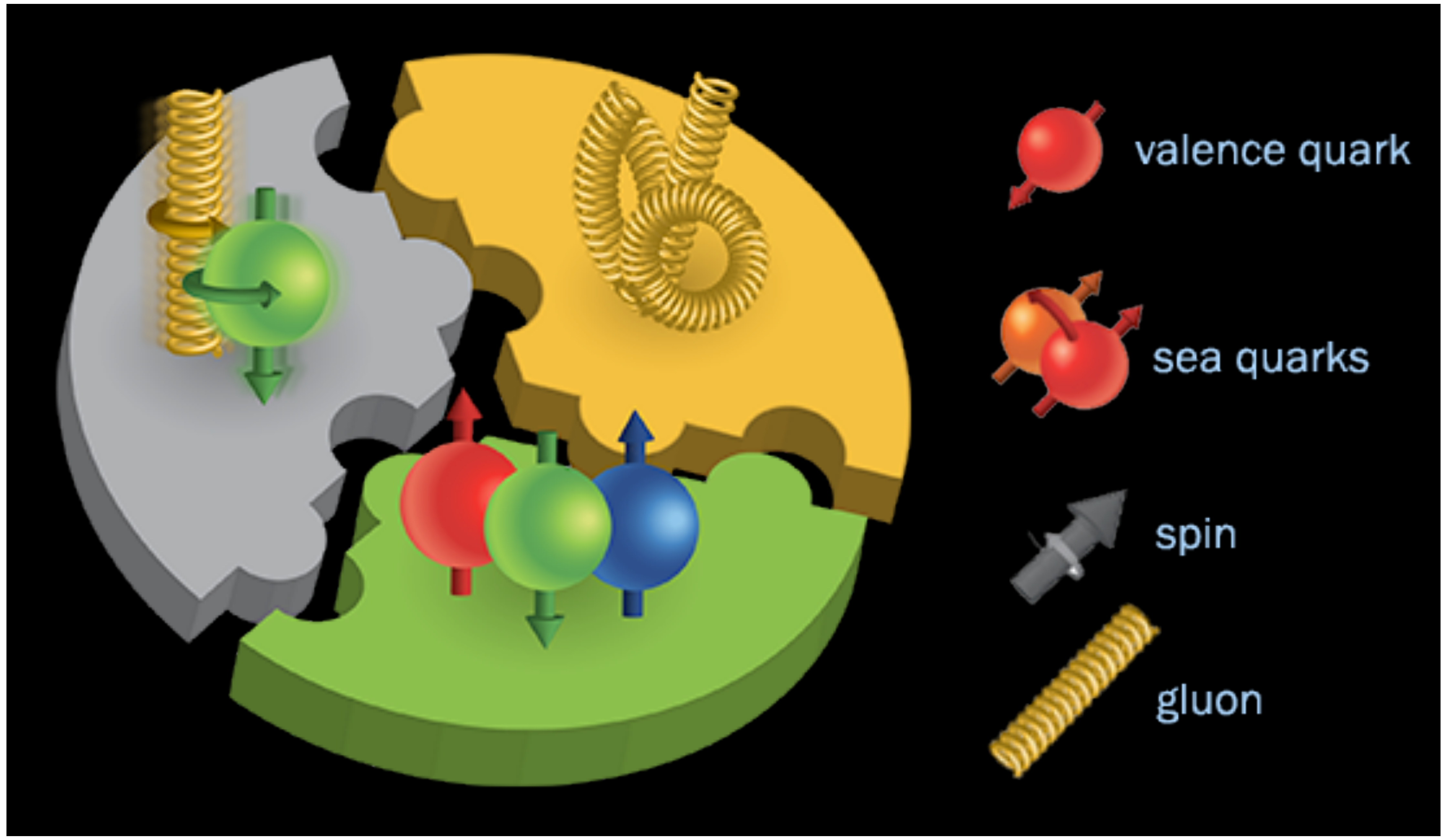
# To Get Kids Interested in Science, We Have to Let Them Do Science

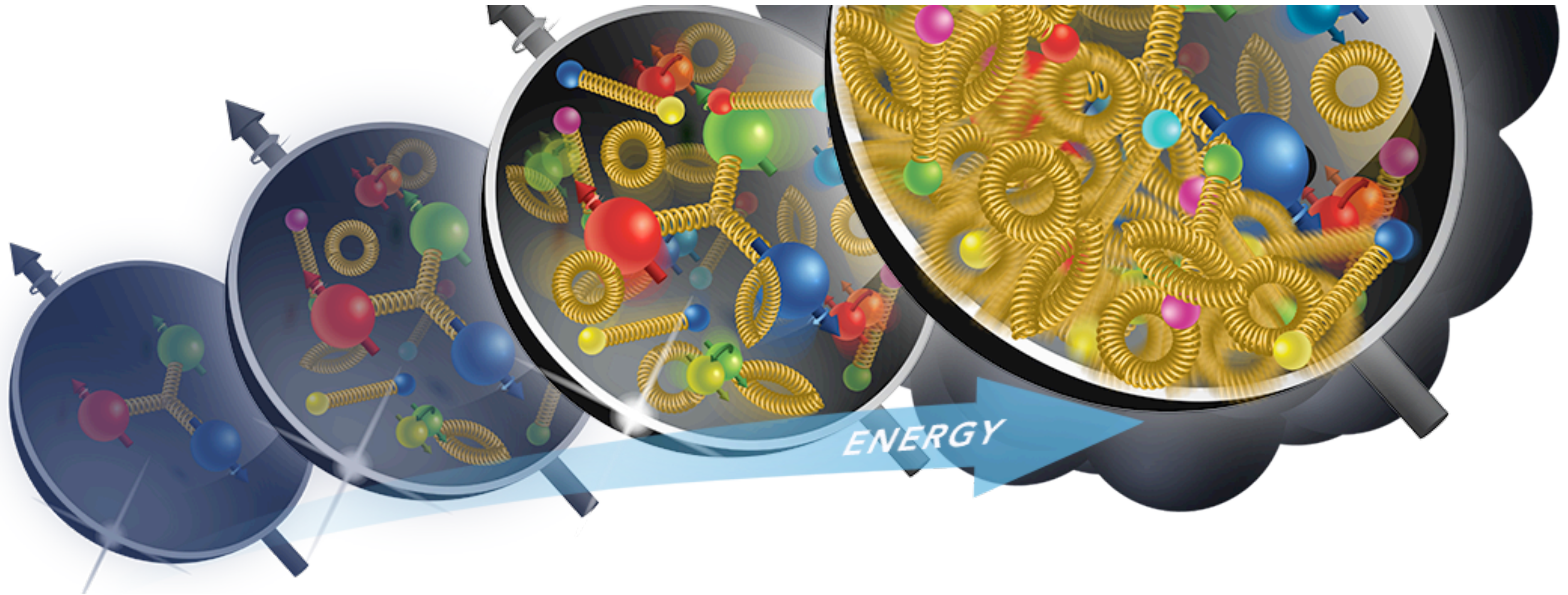
A pilot program for high schoolers offers a blueprint in getting students involved in cutting-edge particle physics research

BY RAGHAV KUNNAWALKAM ELAYAVALLI

- https://www.scientificamerican.com/article/to-get-kids-interested-in-science-we-have-to-let-them-do-science/

# Why EIC?




- With a start time of early 2030s - the success of EIC depends on the availability of a well educated, computationally robust and diverse scientific workforce - emphasized in 2023 LRP
- Future facilities are useful to raise awareness of the science to the younger generation by giving them something to aim for!
- Give them an opportunity to experience current research amidst the physics knowledge that one might learn from a text book.

# How did this start?

- Concept of such a program oriented at high school students originated at Yale during the winter of 2021 for Yale’s Pathways to Science program

- With the announcement of the EIC - current high school students are the ones we all will be hiring as grad students/postdocs/research-scientists to build detectors, do analysis and make discoveries

- Summer of 2022, we ran a workshop for 4 days for 8 high school students at Yale

- Yale Heavy ion group graduate students were instrumental in serving as near-peer mentors to the high school students

# Pathways to Science @ Yale

https://onha.yale.edu/initiatives/public-schools-and-youth/pathways-science

- Program underway at Yale for a long time proving opportunities to New Haven Magnet high school students

- Offers research experience followed by admission into top colleges and universities

- Each day had the students attend a short lecture of the topic followed by hands on sessions.

- We also built in a gap day during the week which included a tour of the Wright Lab, Yale physics machine shop, accelerator facilities etc…

Summer 2022, Pathways workshop

# School of Science and Math @ Vanderbilt

https://www.vanderbilt.edu/cseo-ssmv/

## Curriculum

In **Interdisciplinary Science-I,** students participate in classroom experiments where they may, for example, extract caffeine from tea leaves during a chemistry lab as a part of a multidisciplinary study of addiction. In addition, guest scientists, physicians, post-doctoral fellows, and graduate students from Vanderbilt University and Vanderbilt University Medical Center visit the class or host laboratory visits to share their expertise.

**Research I** is a 3-week summer course with a focus on field research that spans a broad array of subjects, including ecology, geology, archaeology, chemistry, forensics, and engineering.

The majority of **Interdisciplinary Science II** is focused on small-group research projects designed to engage students in several scientific and engineering disciplines through generating novel data. In the featured image, students are studying the effects of microplastics on plant growth.

**Research II** is a 3-week summer course that allows students to complete a small-group research project of their choosing and then communicate this research to other students through research poster presentations.

During **Interdisciplinary Science III**, students participate in several teaching modules that explore scientific and engineering innovation at Vanderbilt and beyond, including the various outputs of research such as publications, prototypes, and patents.

**Research III** is a 6-week summer internship in a Vanderbilt laboratory where students work alongside a research team to complete a research project. The results of these projects are submitted to national science competitions where students can earn prestigious recognition and scholarships. Also, much of this work is published in the *Young Scientist* research journal.

The **Advanced Research** course is dedicated to building skills to help students communicate their research not only to the scientific community but also to the broader public. A significant portion of the course concentrates on students participating in ***community-engaged research projects*** that benefit Nashville and beyond.

- Collaboration between Vanderbilt and Metro-Nashville school district
- Students apply for SSMV right as they start high school and selection is very holistic and generalized
- Students spend 1 day per week at Vandy during the semester and essentially do an REU during the summer

# School of Science and Math @ Vanderbilt

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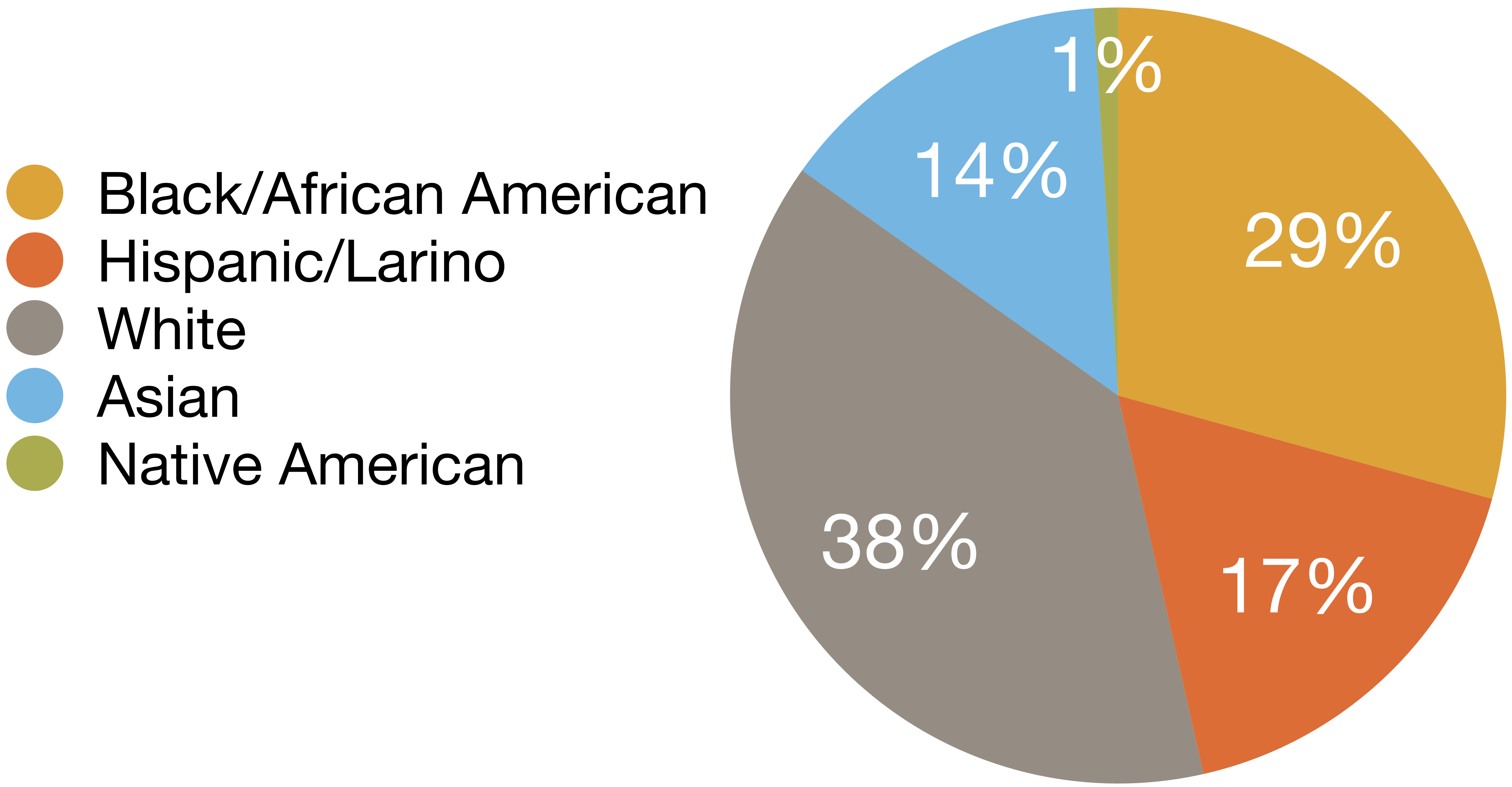


One thing we note is that this is not a sample of average high school student - there is a selection bias on who knows to apply to this program!

Dr. Angela Eeds
(Director, SSMV)

# Workshop - Lets Smash the Proton

- 4-Day workshop : 2-3 hours per day (significant improvement in student performance when workshop is held after lunch)

- We have done it three times now at varying scales

  - Yale 2022 - 8 students

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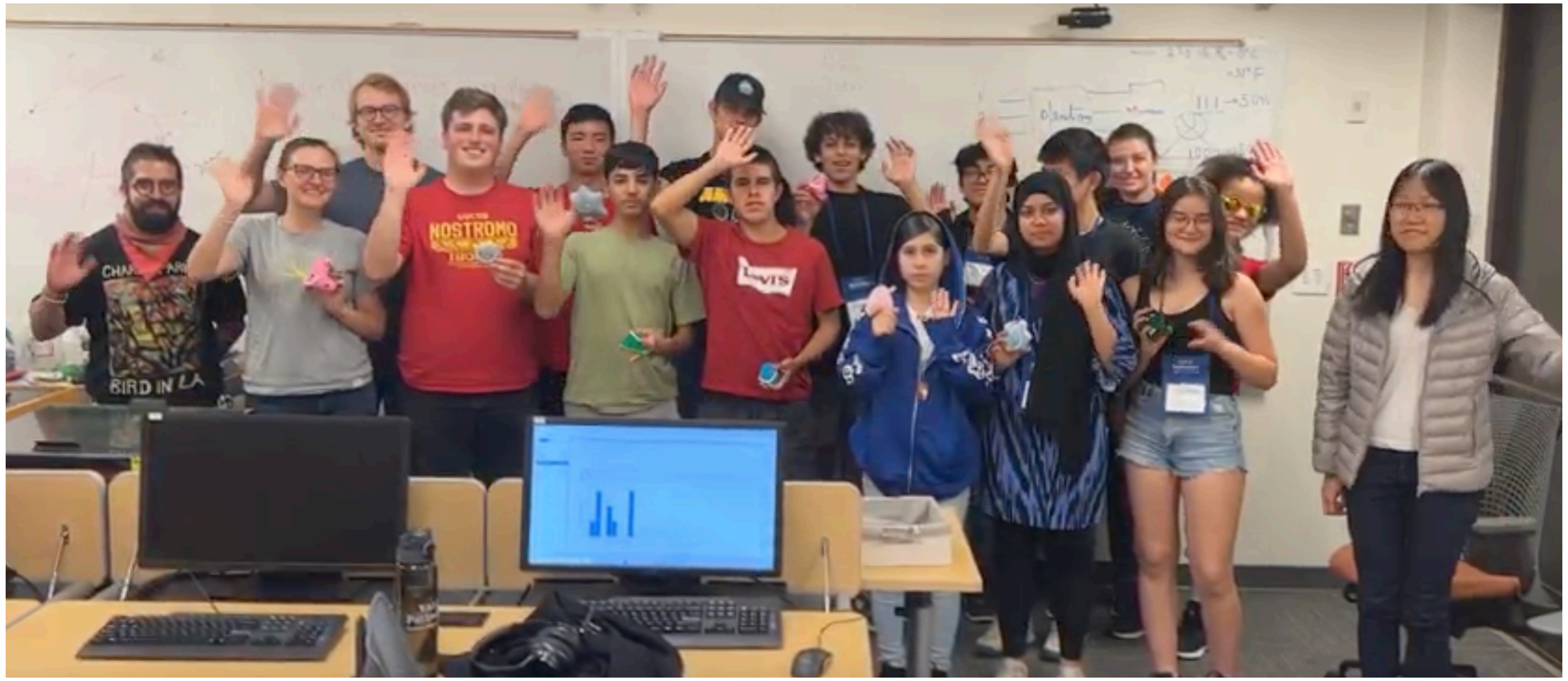
    - Yale 2022 - 8 students, 2023 ~12 students



# Workshop - Lets Smash the Proton

- 4-Day workshop : 2-3 hours per day (significant improvement in student performance when workshop is held after lunch)
- We have done it three times now at varying scales
    - Yale 2022 - 8 students, 2023 ~12 students
    - Vanderbilt 2023 - 24 students (essentially similar numbers from now onwards for every summer)
- For larger number of students -we do smaller groups and each group will focus on a task and present their results at the end of the week
- For the future workshops are Vanderbilt, we are factoring in a trip to Oak Ridge facilitated by Dr. Friederike Bock

# 2023 Workshop @ Vandy

- 24 students - raising sophomores in high school
- Allison Sellers (SSMV Class of 2024) took part as a near-peer mentor to her juniors
- She worked in my group during 2023 and was essentially invaluable to the program!

# Day - 1 ‘Introduction/Basics’

```
[1]: print('Hello World! ')
```

```
Hello World!
```

**Jupyter Notebooks**

This document is called a Jupyter Notebook. It's a convenient way to interact with data within a Python envirnonment. Here is a good tutorial all about notebooks.

Each "cell" can contain either text or code that we wish to execute. You can select the type of cell in the pull-down menu above.

To execute a code cell, hit "Shift+Enter".

To see a list of commands, click the Help pull-down menu above.

- It all starts with python and line by line interpreter in the Jupyter notebooks!

- The software is run via a binder on a remote machine (used to be better due to google funds but its problematic now…)

## Import required libraries

Python allows users to import libraries containing various functions. The syntax for this is:

```
import library_name
from library_name import function
```

Python has a number of powerful libraries for handling data. The most commonly used modules are called `numpy`, `pandas`, and `matplotlib`.

**numpy**

numpy is a powerful library geared to numerical analysis of arrays of data.

**pandas**

Pandas is a data-oriented library based around a set of core data structures. The main structure is called a `DataFrame`, which is a 2D tabular-like structure.

There are very simple tools to read in common data formats into Pandas. In this lab we will use the `pd.read_csv` function to load data from a text file.

**matplotlib**

We will use matplotlib to plot and display the data and the fit results. We will load the `pyplot` submodule which provides key plotting tools for us.

Python 3 (ipykernel)

# Day - 1 ‘Introduction/Basics’

## Simulating electron - proton collisions

### Day-1 : Introduction and first run

We will first initialize our simulation toolkit - PYTHIA (pythia.org) and run a few collisions of electrons and protons at varying energies and begin to study the output

In [2]:
```
# Importing useful headers
import pythia8
import numpy as np
import matplotlib.pyplot as plt
import pandas as pd
```

- This is pretty useful for several other things as well! One can run pythia, fastjet, root, all on the browser for your quick cross-checks or early training of undergrads/grads

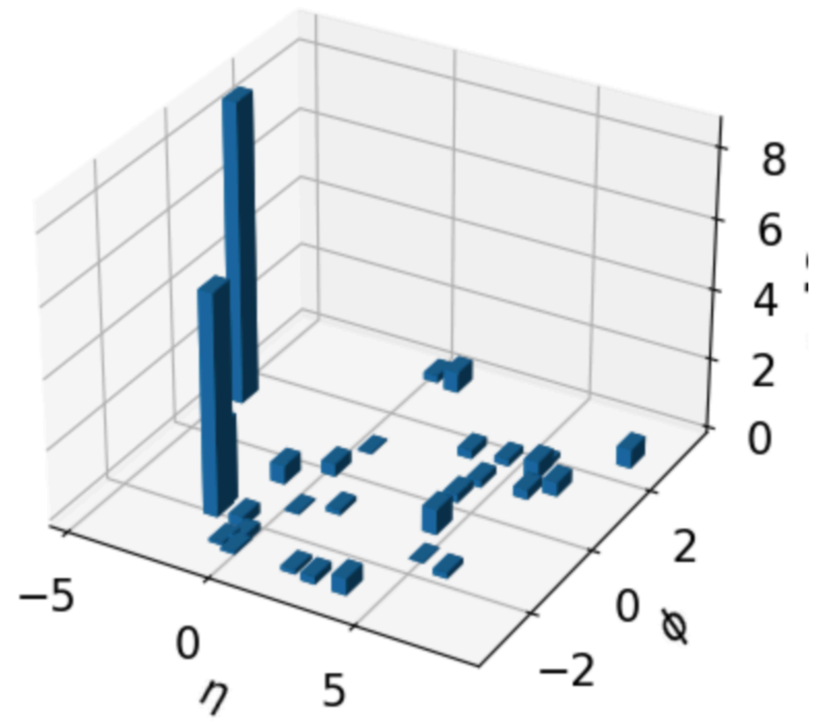
# Day - 2 ‘Whats produced in e-p’

[18]:
```
Event_Particles = pd.DataFrame(particles, columns=['ID','pT','phi','eta','theta','Energy', 'momentum','mass'])
Event_Particles
```

[18]:

| | ID | pT | phi | eta | theta | Energy | momentum | mass |
|---|---|---|---|---|---|---|---|---|
| 0 | 11.0 | 8.0300 | -2.6800 | -0.664 | 2.19000 | 9.8700 | 9.8700 | 0.000511 |
| 1 | -321.0 | 0.4910 | 0.3540 | 0.998 | 0.70600 | 0.9030 | 0.7560 | 0.494000 |
| 2 | 211.0 | 0.0742 | -0.0592 | 6.720 | 0.00241 | 30.8000 | 30.8000 | 0.140000 |
| 3 | 2112.0 | 0.6020 | 2.6400 | 5.250 | 0.01050 | 57.2000 | 57.2000 | 0.940000 |
| 4 | 211.0 | 0.6900 | 0.7550 | 1.110 | 0.63500 | 1.1700 | 1.1600 | 0.140000 |
| 5 | 22.0 | 0.2660 | 1.7900 | 1.830 | 0.31900 | 0.8490 | 0.8490 | 0.000000 |
| 6 | 22.0 | 0.1220 | 1.0200 | 1.840 | 0.31500 | 0.3930 | 0.3930 | 0.000000 |
| 7 | 22.0 | 4.5300 | 0.3620 | 0.568 | 1.03000 | 5.2800 | 5.2800 | 0.000000 |
| 8 | 22.0 | 0.7210 | 0.2940 | 0.536 | 1.06000 | 0.8270 | 0.8270 | 0.000000 |
| 9 | 22.0 | 0.8000 | 0.4130 | 0.839 | 0.81600 | 1.1000 | 1.1000 | 0.000000 |
| 10 | 22.0 | 0.2360 | 0.5900 | 1.090 | 0.64700 | 0.3910 | 0.3910 | 0.000000 |
| 11 | 22.0 | 0.8080 | 0.0248 | 0.856 | 0.80300 | 1.1200 | 1.1200 | 0.000000 |
| 12 | 22.0 | 0.0261 | -0.8130 | 0.412 | 1.17000 | 0.0284 | 0.0284 | 0.000000 |

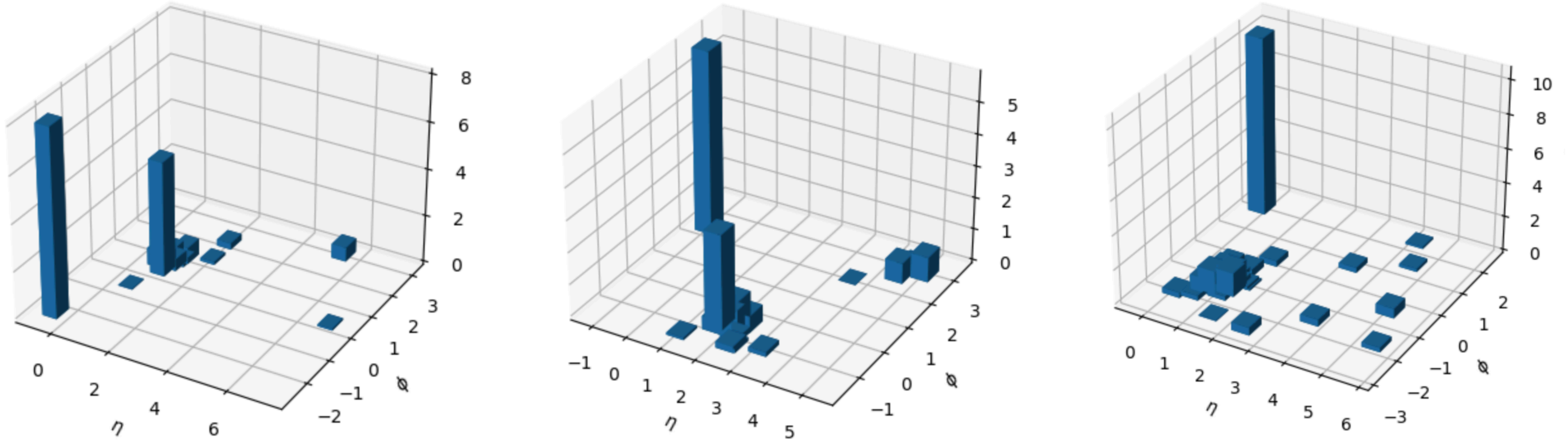
In [18]:
```
fig = plt.figure()
ax = fig.add_subplot(111, projection='3d')

# Data for three-dimensional scattered points
zdata = Event_Particles['pT']
xdata = Event_Particles['eta']
ydata = Event_Particles['phi']
n = Event_Particles.shape[0]
ax.bar3d(xdata,ydata,np.zeros(n),np.ones(n)*0.5,np.ones(n)*0.5,zdata)
ax.set_xlabel('$\eta$')
ax.set_ylabel('$\phi$')
ax.set_zlabel('$p_T$ [GeV]')
plt.show()
```




- Students focus on how to present information in a useful form - PLOTS!

# Day - 2 ‘Statistics and Randomness’

```python
pythia.init()
pythia.readString("Random:setSeed = on")
pythia.readString("Random:seed = 389780") # add your birthday
```




- Einstein - “God does not play dice” -> probabilities inherent in the quantum world

# 2023 Workshop @ Vandy

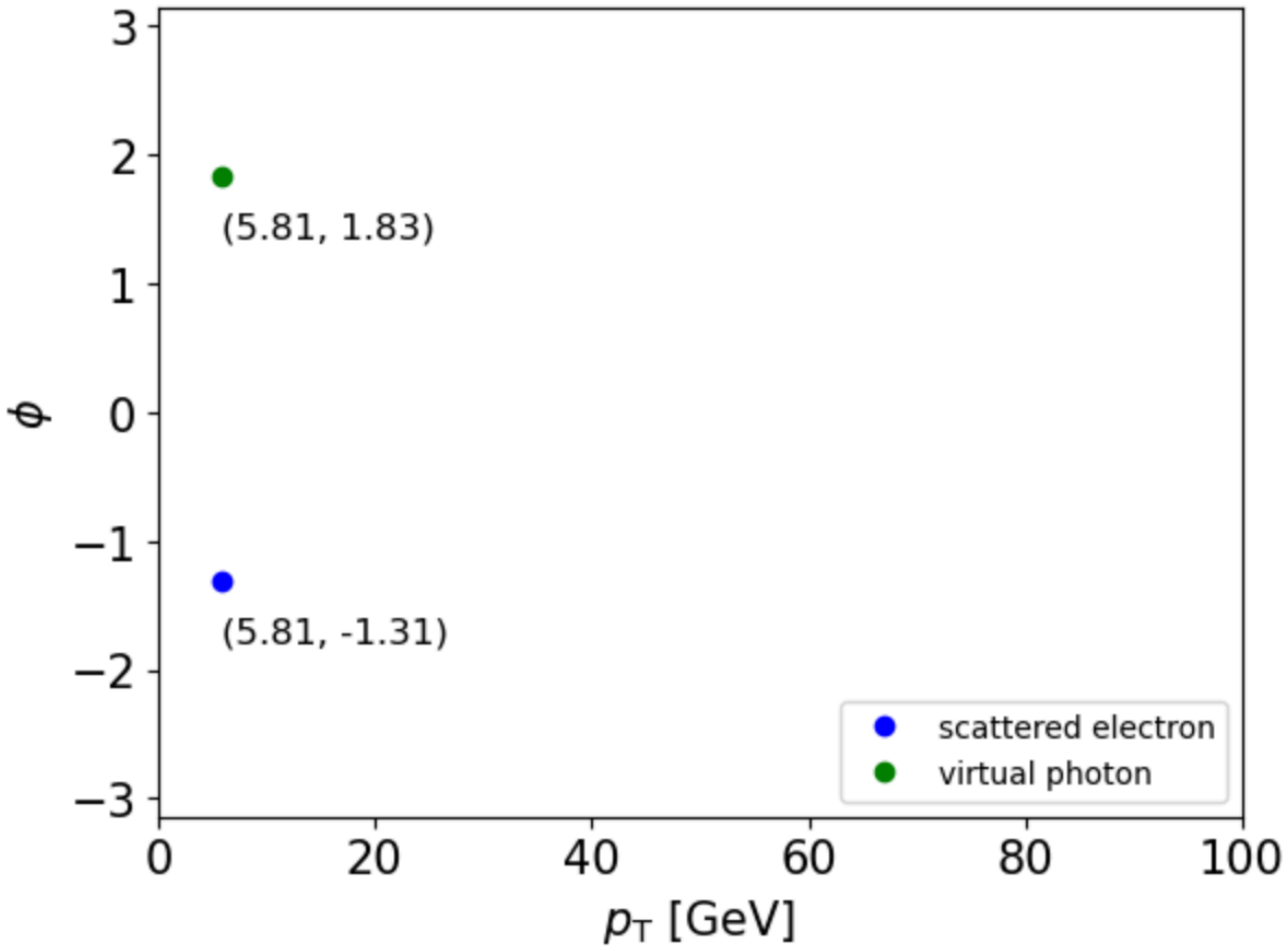


- Note the active use of PDG books and students running/playing with the code!

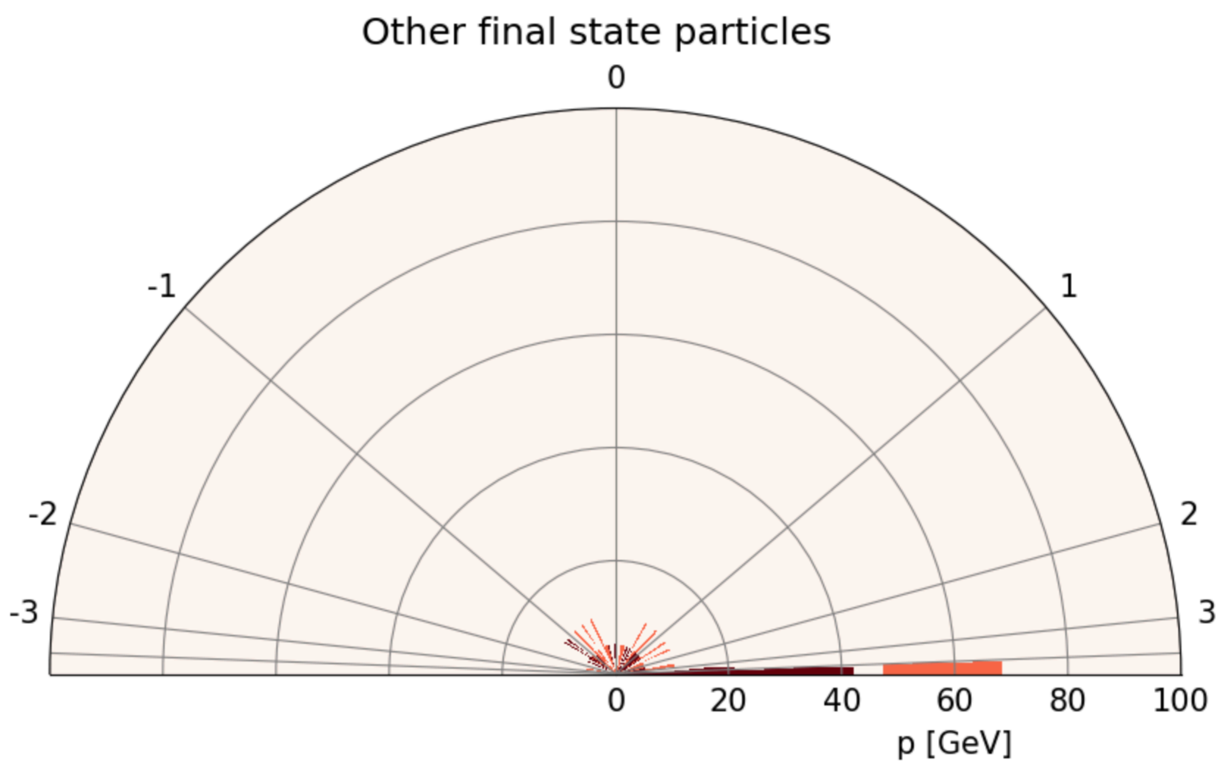
# Day - 3 'Physics from particles'

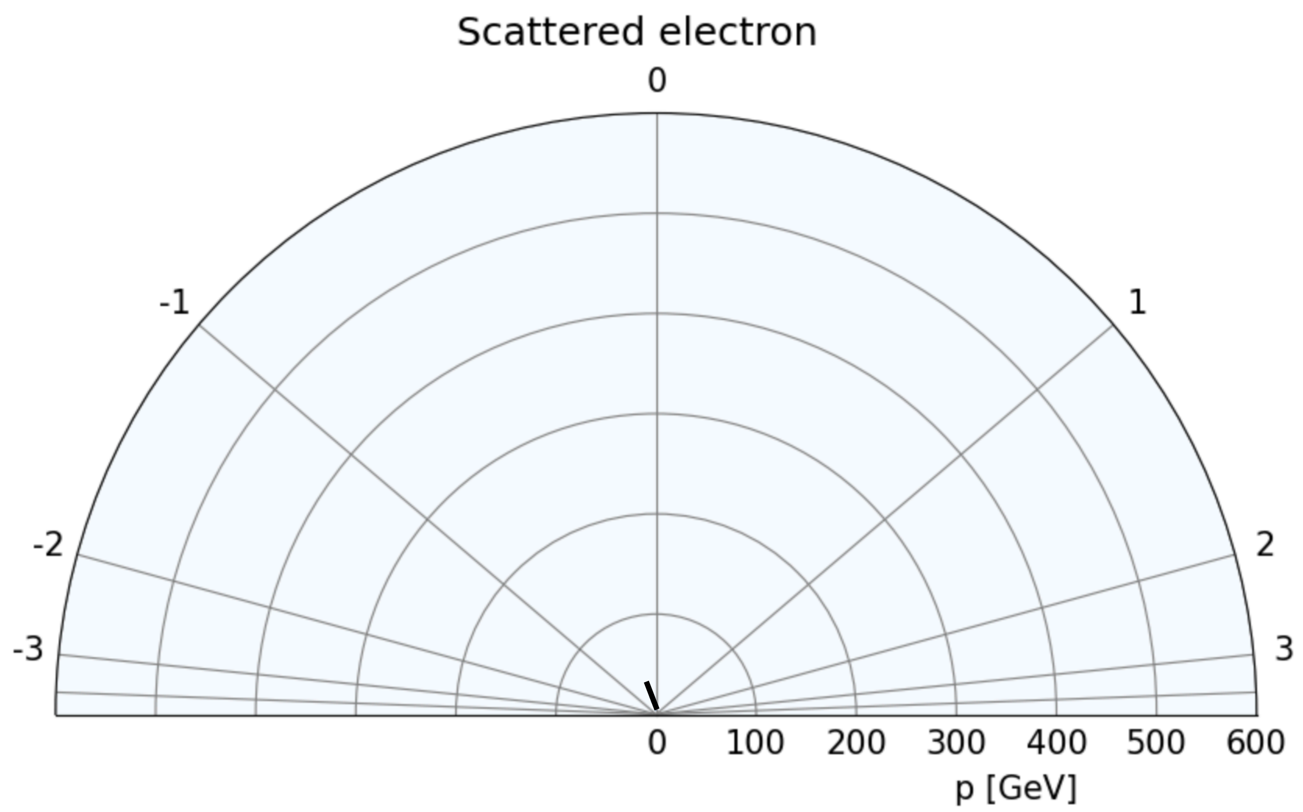
# Day - 3 ‘Physics from particles’

```
In [21]: plt.plot(electron_out.pT(), electron_out.phi(), 'bo', label='scattered electron')
plt.plot(photon.pT(), photon.phi(), 'go', label='virtual photon')
A = [electron_out.pT(), photon.pT()]
B = [electron_out.phi(), photon.phi()]
plt.xlim(0,100)
plt.ylim(-np.pi, np.pi)
plt.legend(fontsize=10, loc='lower right')
plt.xlabel('$p_\mathrm{T}$ [GeV]')
plt.ylabel('$\phi$')
for xy in zip(A, B):
    plt.annotate('(%.2f, %.2f)' % xy, xy=xy, xytext=(0,-20), textcoords='offset points', fontsize=12)
```




- Momentum conservation
- What type of particles are produced in and where do they end up?



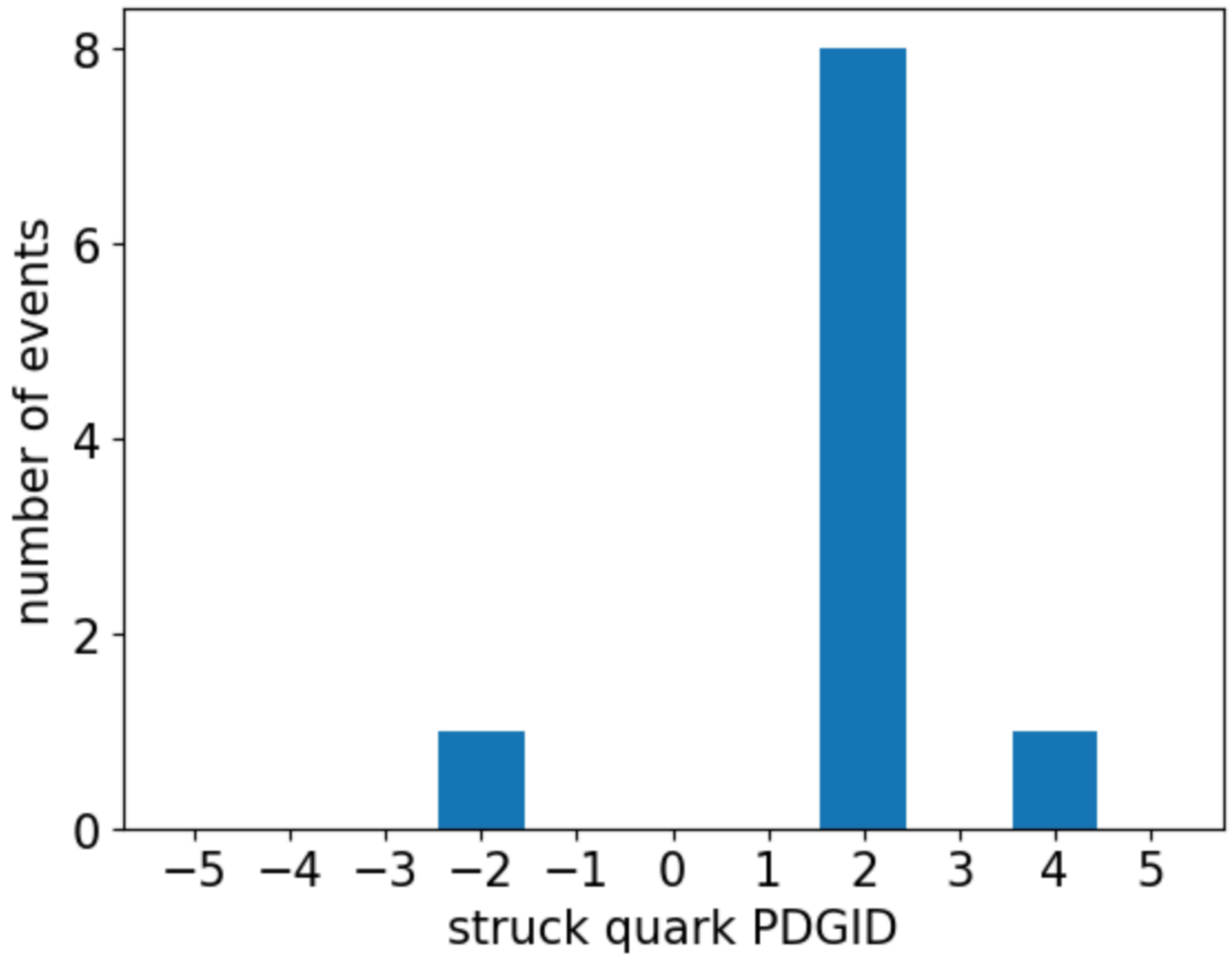
# Day - 4 'Whats inside the proton'

```
delphi = []
deleta = []
scattered_pT = []
photon_pT = []
quark_pid = []

Number_of_events = 100

# Begin event loop. Generate event. Skip if error.
for iEvent in range(0, Number_of_events):
    if not pythia.next():
        continue
    proton = pythia.event[1].p()
    electron_in = pythia.event[4].p()
    electron_out = pythia.event[6].p()
    photon = electron_in - electron_out
    deta = photon.eta()
    dphi = photon.phi()
    if dphi > 3.1415:
        dphi = 6.2832 - dphi
    delphi.append(dphi)
    deleta.append(deta)
    scattered_pT.append(electron_out.pT())
    photon_pT.append(photon.pT())
    quark_pid.append(pythia.event[5].id())

delphi = np.array(delphi)
deleta = np.array(deleta)
scattered_pT = np.array(scattered_pT)
photon_pT = np.array(photon_pT)
quark_pid = np.array(quark_pid)
# End of event loop. Statistics. Histogram. Done.
pythia.stat()
```




- 'how did you get a charm quark??? Tell me your seed!'

# Day - 4 ‘Whats inside the proton’

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delphi = np.array(delphi)
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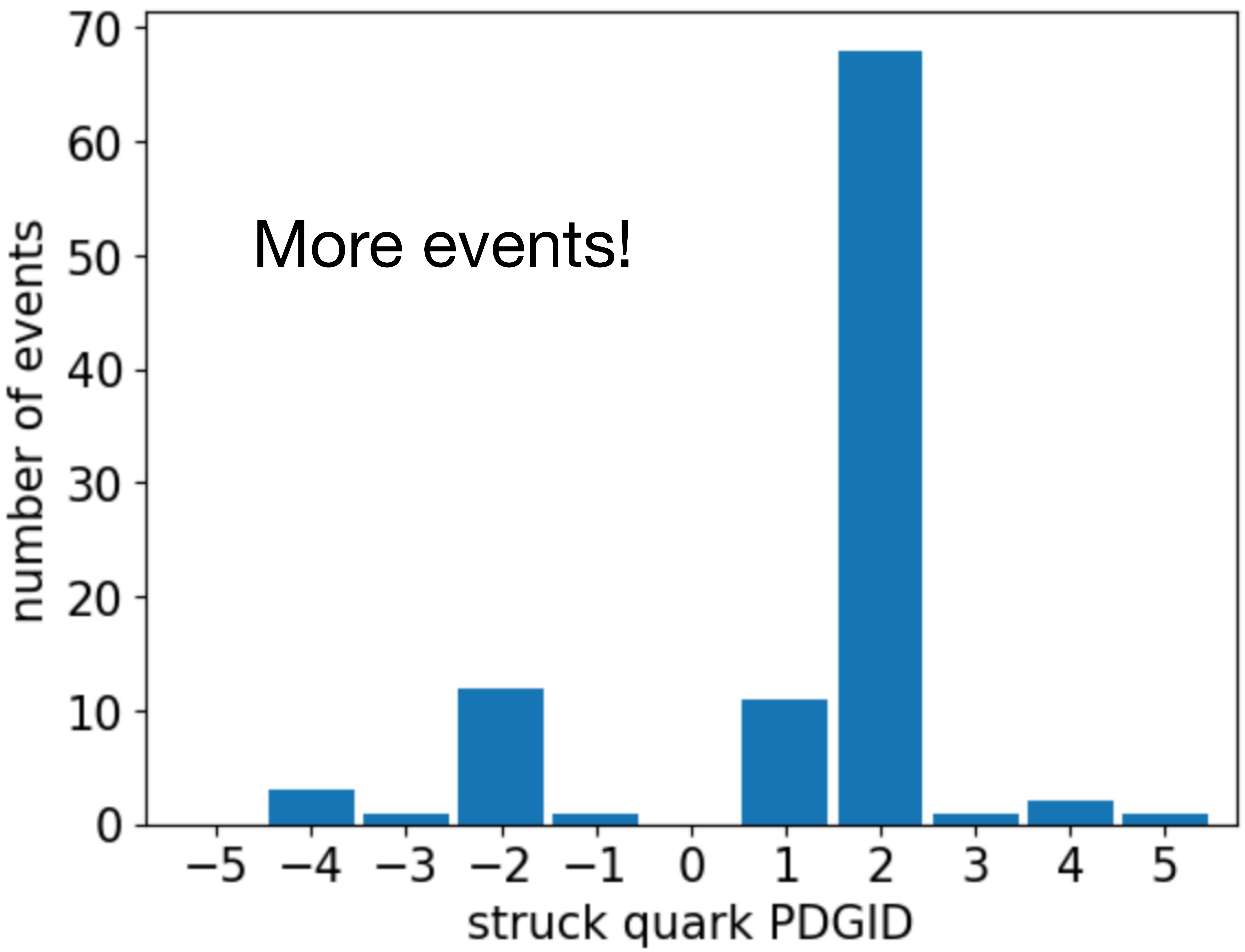
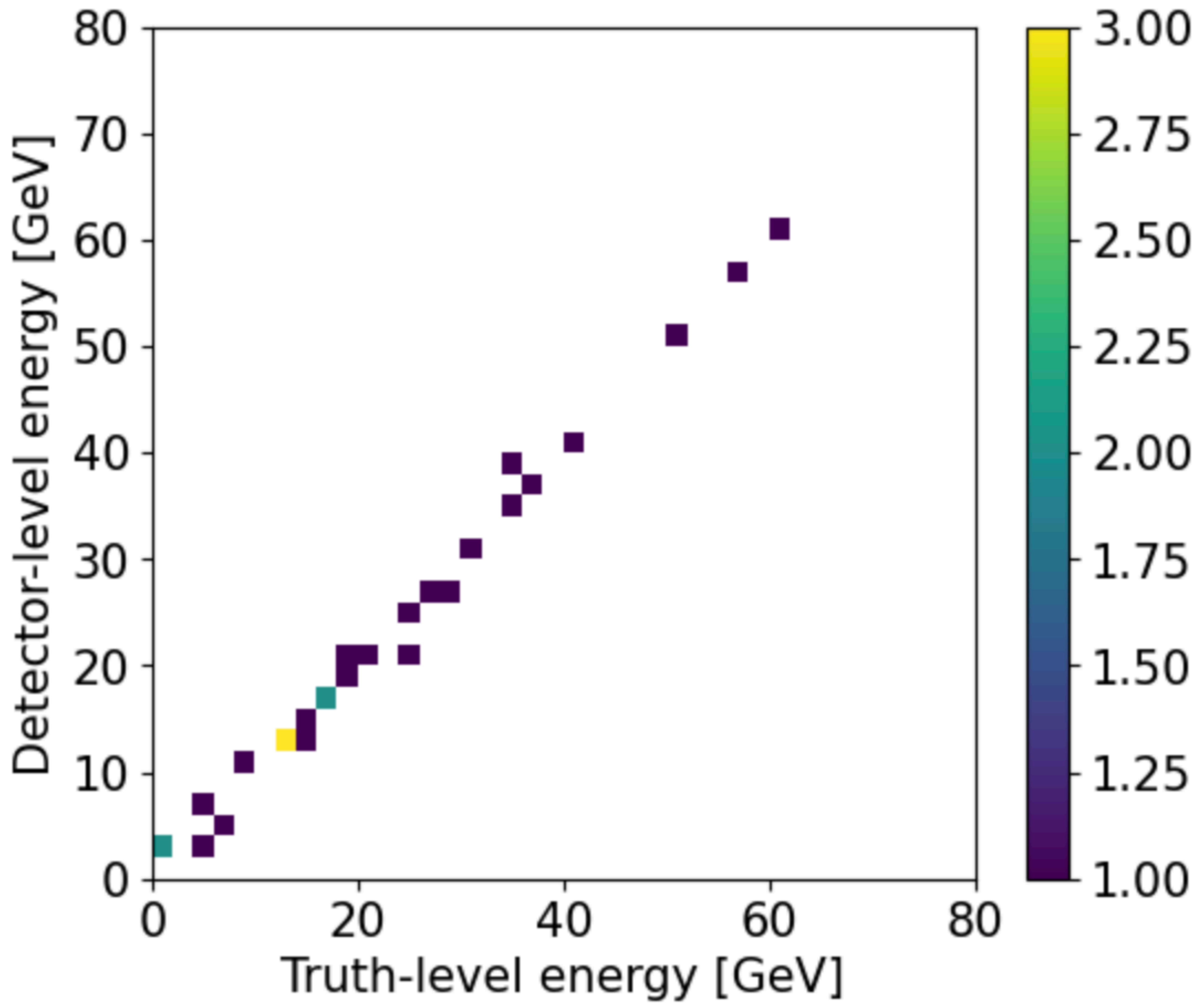
```



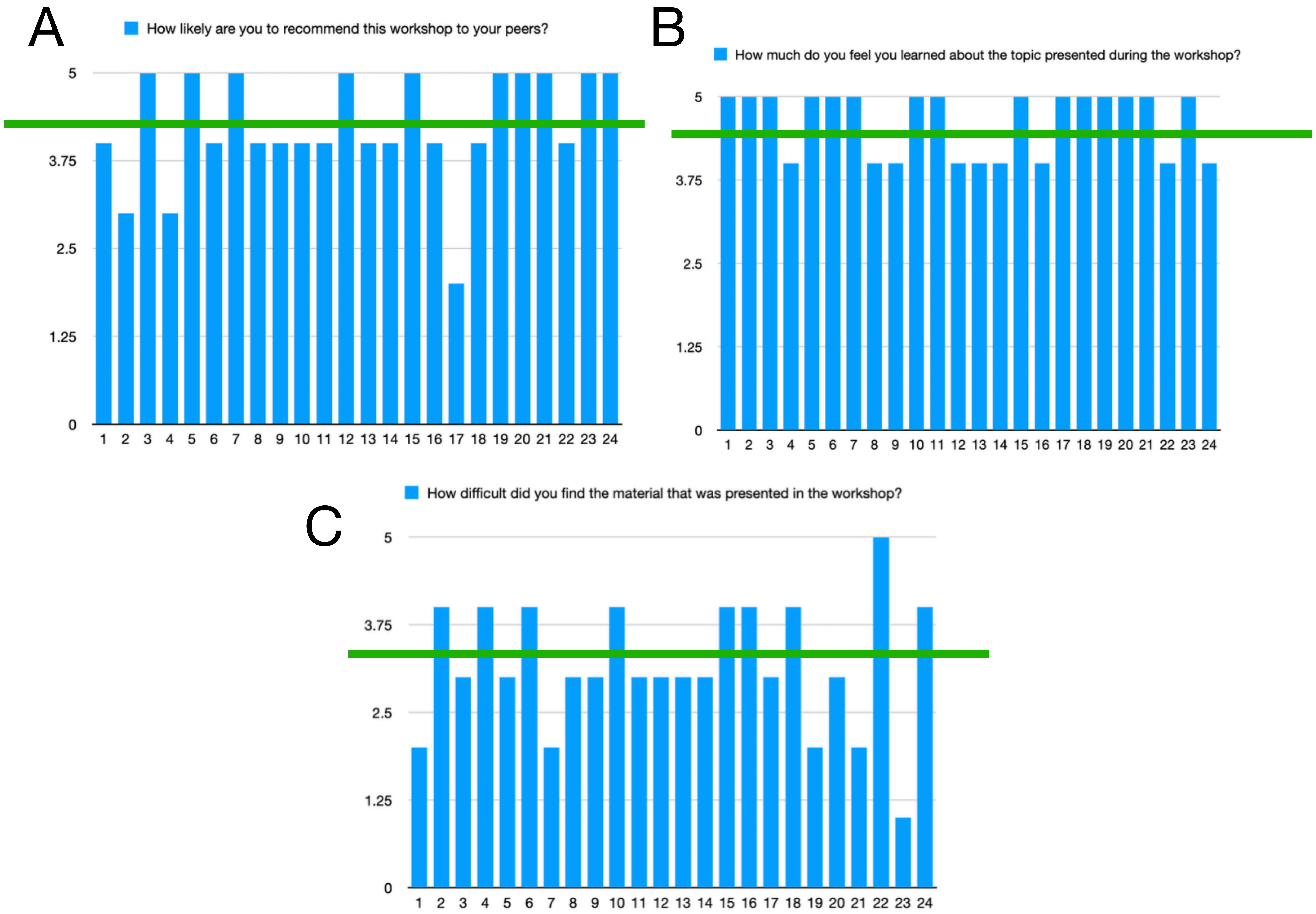
# Day - 4 'Measuring particles and detectors'




- How do we get reality from the simulation - Detectors
- particles - charged and neutral
- Detectors - trackers and calorimeters
- Efficiency and smearing
- Credit - Youqi Song (Yale) for the code :)

# Group presentation on results!

# Student Feedback from Year-0




- We collect daily feedback from the students both for quantitative questions -

    A. How likely are you to recommend this workshop to your peers

    B. How much do you feel you learned about the topic

    C. How difficult did you find the material

- Students learned a lot, found it *not* easy and are happy to recommend it to their peers

# Student Feedback from Year-0

- I liked the workshop and how everyday we did a little lecture then we worked on the notebook. I would not change anything about the how the workshop was delivered because even if you needed help it was enough people there that could help.
- I loved this workshop! I would suggest going a little slower in the future to make sure everyone understands everything.
- I would recommend further explaining some of the basics of physics. I tended to understand many of the major points of the lectures, but I struggled some with the small details and some of the basic mechanics of the molecules. This workshop was super intriguing and interesting, while also totally mind boggling, which isn't always a bad thing. Overall, I enjoyed learning about this type of physics and interacting with Python at this workshop. It has managed to further interest me into particle physics, a field I previously knew little about. On recommending this workshop to my peers, I don't know that I would. It was very enlightening, but it was also very complex and a lot at times. However, I would definitely recommend it to those who had previously taken Physics and were looking to explore a career in Physics.
- I enjoyed the workshop a lot as it was educational and made seemingly complex topics more simple to understand. There were plenty of opportunities to ask questions and we were able to actively participate by modeling the particle collisions with pythia.
- The format of the workshop enabled us to speak about the subject at hand confidently. I learned with Dr. Raghav when you answer you have to do it with confidence. This is a very valuable lesson to learn as for changing it I would just make the days longer.
- Overall it was a very educational and interesting workshop, but if I would change anything I would have the graphs be explained a little more.
- I really enjoyed the workshop. I felt that I was not only learning, but also having a lot of fun learning the material because I was actually able to apply it to coding, and I also enjoyed the process of making mistakes and then learning how to correct them.
- I enjoyed the constant use of analogies, reference to topics discussed previously in the lecture, refreshers at the beginning of the lecture, a wide variety of staff and helpers who were specialized in different fields but gave valuable advice, and the use of time being purposely used more in the physical simulation portion of the workshop. The only thing I would change would be the use of other hands-on activities being implemented into the workshop such as the possible cloud chamber demonstration Dr. Raghav discussed for future iterations of the workshop.

- Freeform questions where students can give anonymized thoughts about the workshop - lot of critical feedback on improving the format/discussions etc…

# How to run this at your institution?

## Everything necessary is available on GitHub

*GitHub - rkunnawa/ssmv_eic*

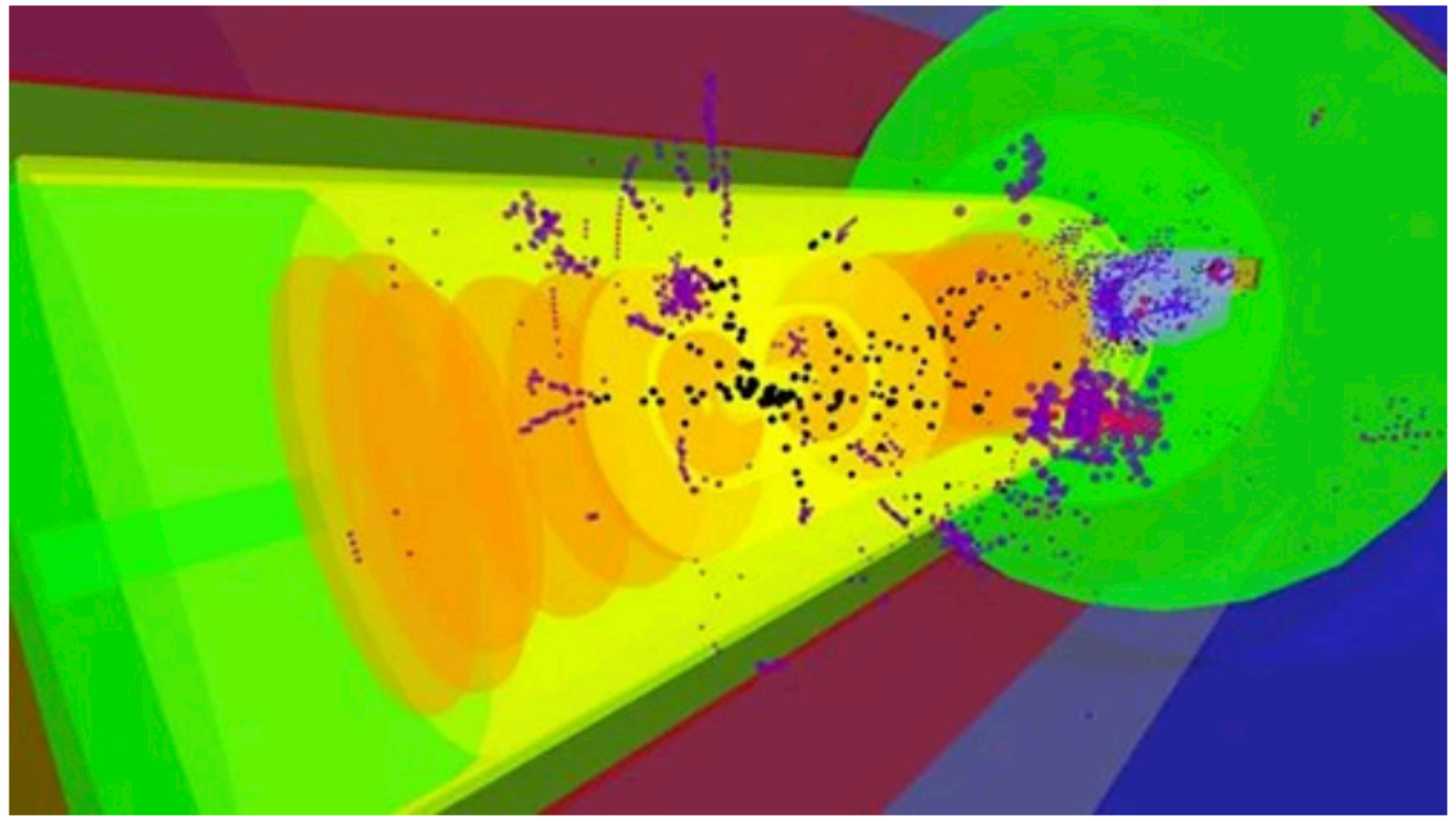
- Software is relatively straightforward - might need improvements with remote machine capability
- Existing programs for high school students in the area! So these can be an addition!
- Send me your undergrads so they can train to be mentors (potentially have funds in the near future)
- I can send you folks who have experience with running this program

*Binder for Jupyter notebooks*

# Potential improvements - 1

Augmented Reality headsets - exploring the e-p collision

https://www.bnl.gov/newsroom/news.php?a=221621

Electron-proton collisions result in a spray of "hits" or points. (Brookhaven National Lab)

- Easily doable with cell phones and open source codes!

# Potential improvements - 2

Physical detectors - cloud chambers, muon counters and more!


- Already included in Yale's version of the program!

# Conclusions

- We are in an exciting time w.r.t EIC physics and its start as the next premier nuclear facility
- High school students now are the future scientific workforce necessary for discovery science
- A lot of different groups are engaged in outreach and this is one such example that I aim to expanded further
- Its a lot of fun!
- And feel free to ping me on any details as its all open source!