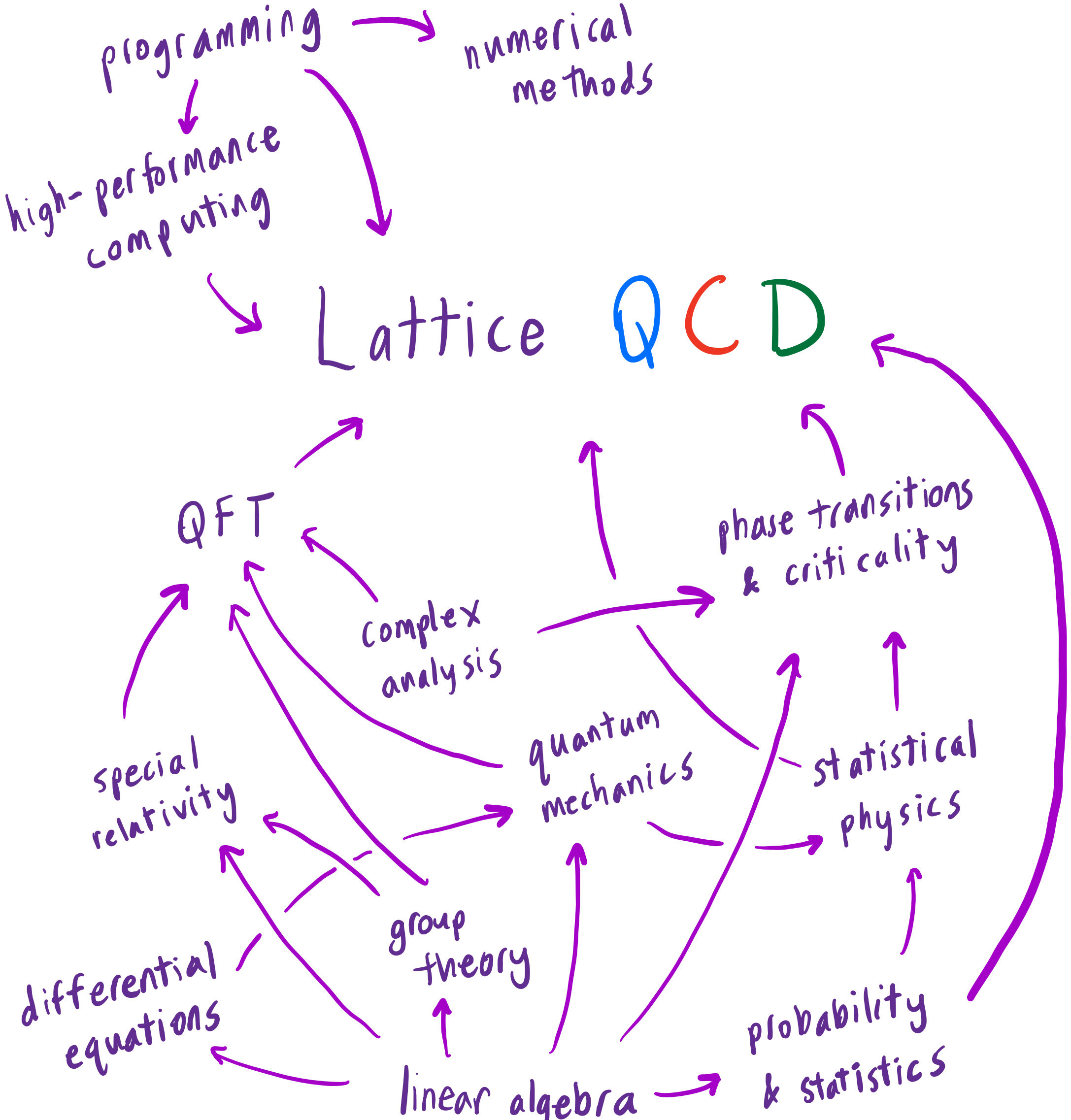
SCIENCE RESEARCH INITIATIVE

THE UNIVERSITY OF UTAH

Simulating Reality: Computational Particle Physics Research with First-Year Undergrads

David A. Clarke



- I research lattice QCD, which I'll desribe shortly
- For now: Used to research strong interaction, e.g. QCD phase diagram, hadron masses, form factors…
- **BUT:** it lies at the nexus of a bunch of advanced topics
- Hence, professors tend to think undergrads can't participate

To help facilitate student involvement: **SRI**

- SRI is a program at University of Utah
- Targets first- and second-year STEM majors
- Idea is to give beginning students **exposure** to research:
  - **Retention** in science major
  - **Motivation** for coursework
  - Cohort building: **community** and **culture**
- Research experiences organized into **streams**, I'm a **stream leader**

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Make it maximally accessible to students

- Unlike "traditional" research experience, **no requirements** like GPA or coursework

How is the SRI doing?

- Program is 3 years old
- In that time, grown from ~30 to ~300 students
- ~70% college of science, ~20% undeclared
- ~15% physicists
- ~30 streams
- In some cases, tangible results such as **paper authorships**
- 98% student satisfaction

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SRI website

SRI leadership

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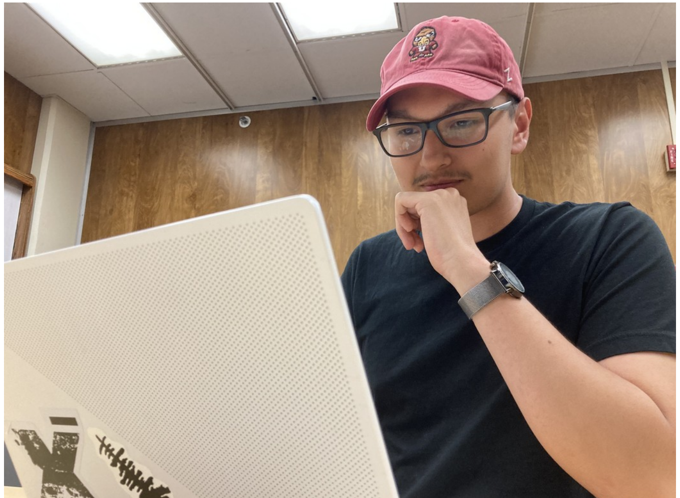
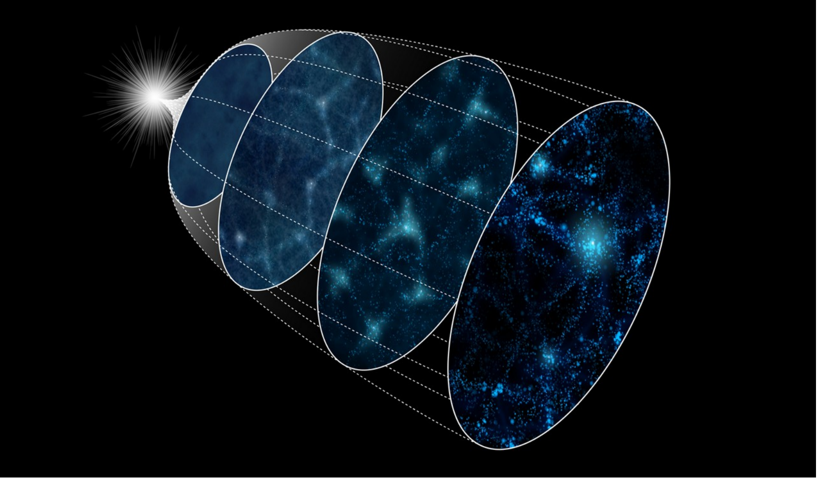
Challenge: Participation in lattice QCD without taking graduate courses

- Try to develop (mostly heuristic) understanding of background physics
- Heuristic understanding of lattice QCD (physically motivated analogies)
- Reorganize research into smaller tasks with clear goals

For example...

Students: Coleman, Kai, Daeton





Early universe

Credit: The Institute of Statistical Mathematics

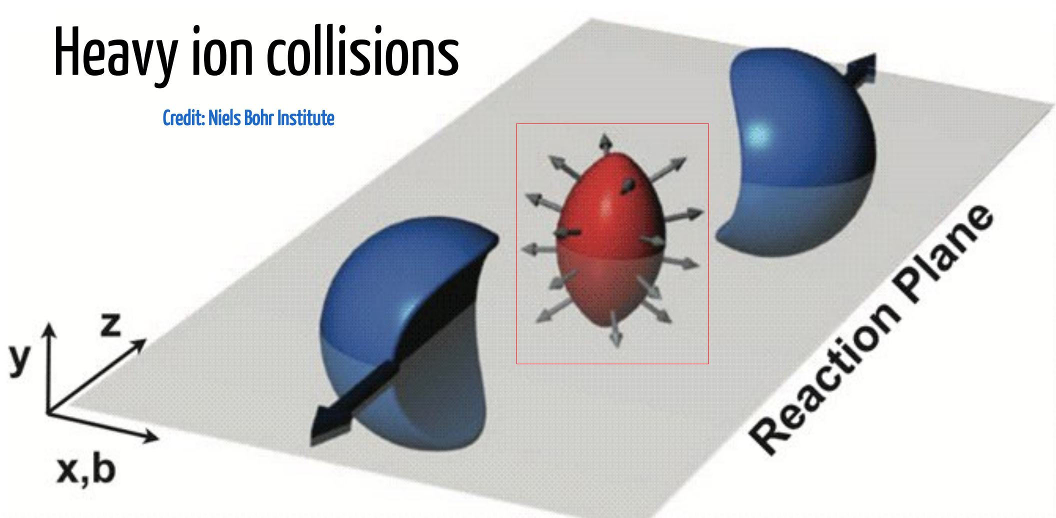
Nuclear matter

Very dense

Very hot

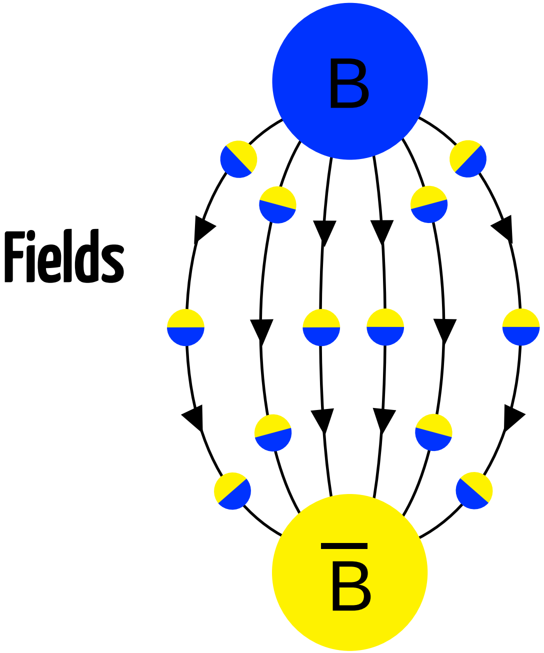
Heavy ion collisions

Credit: Niels Bohr Institute

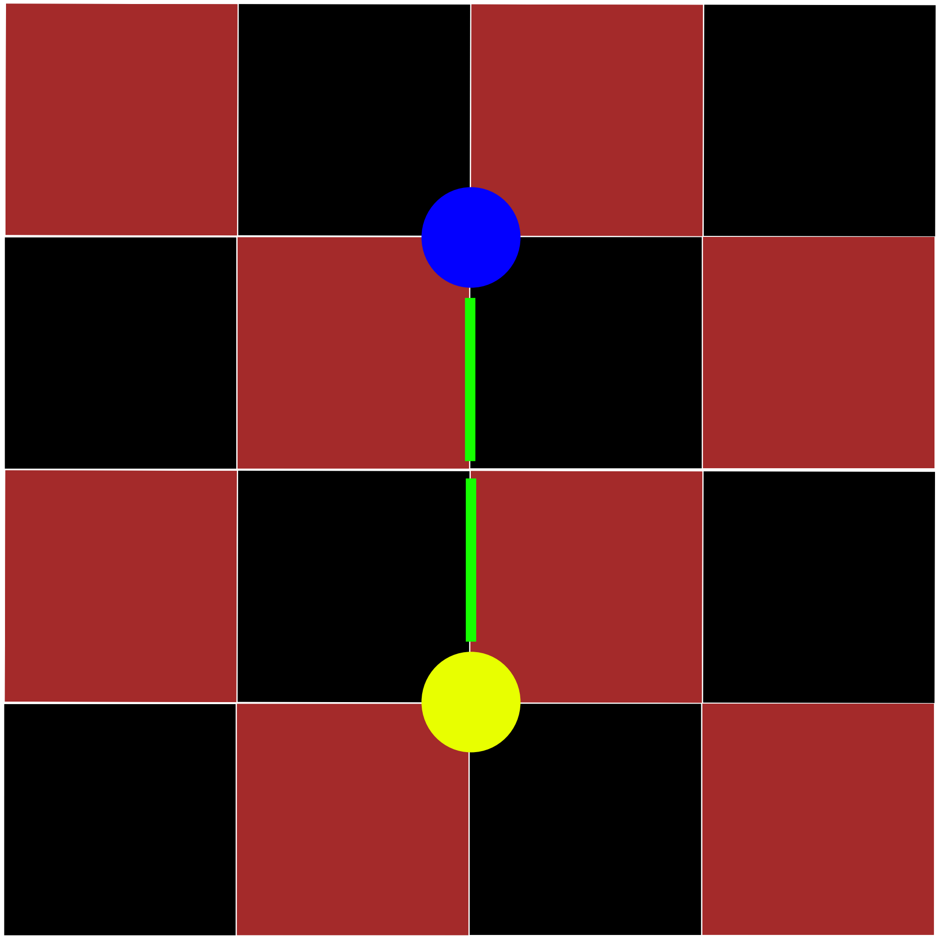


Neutron stars

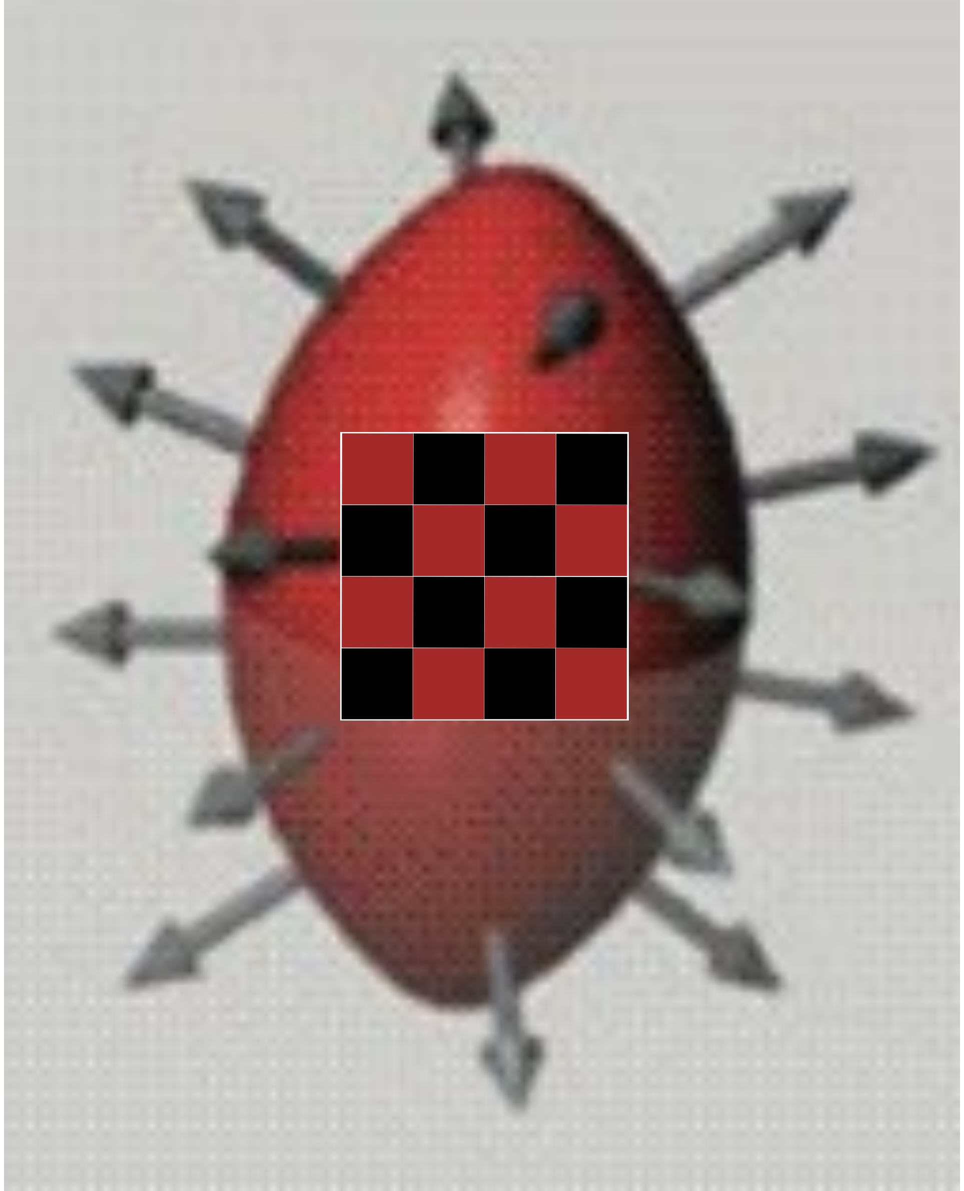
Credit: Wikipedia

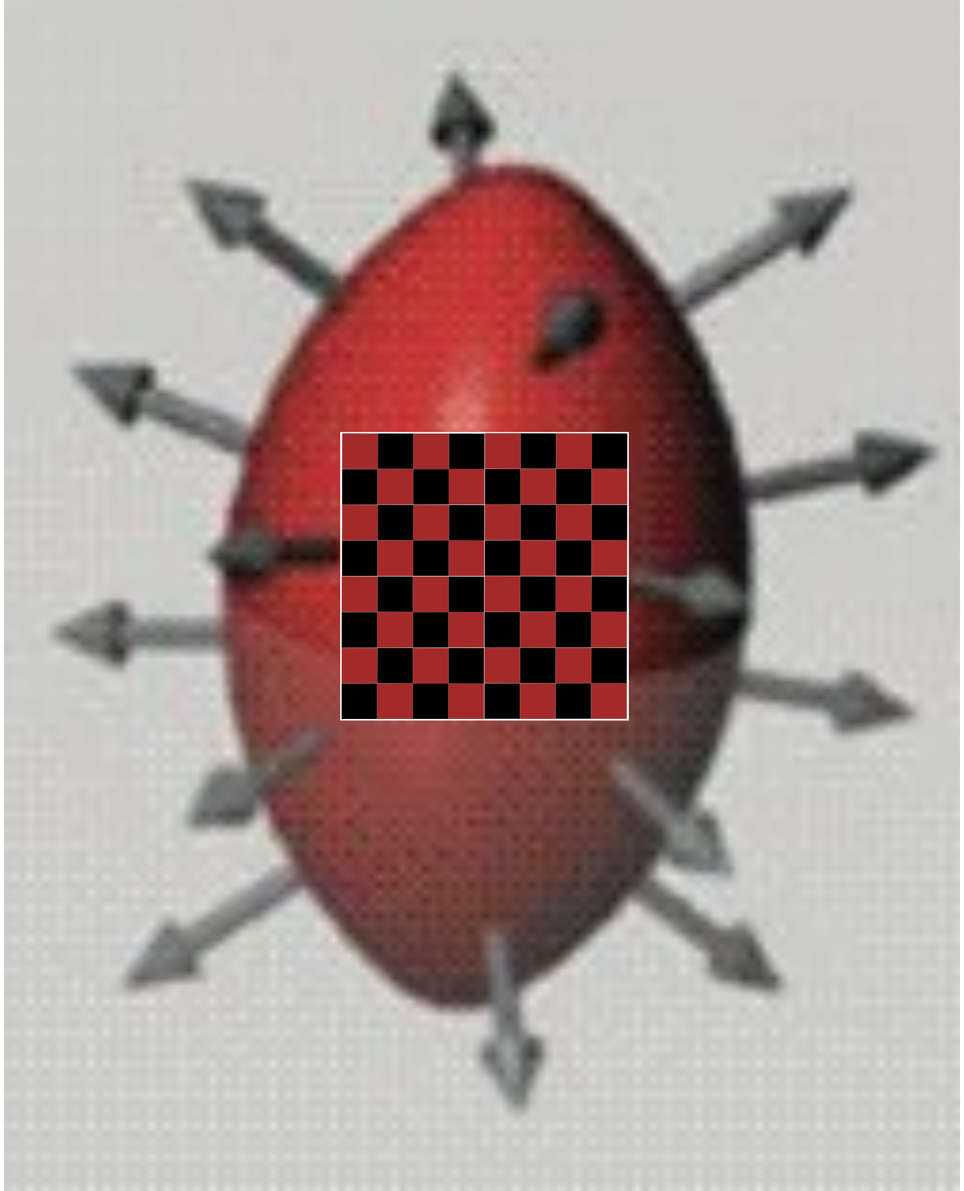


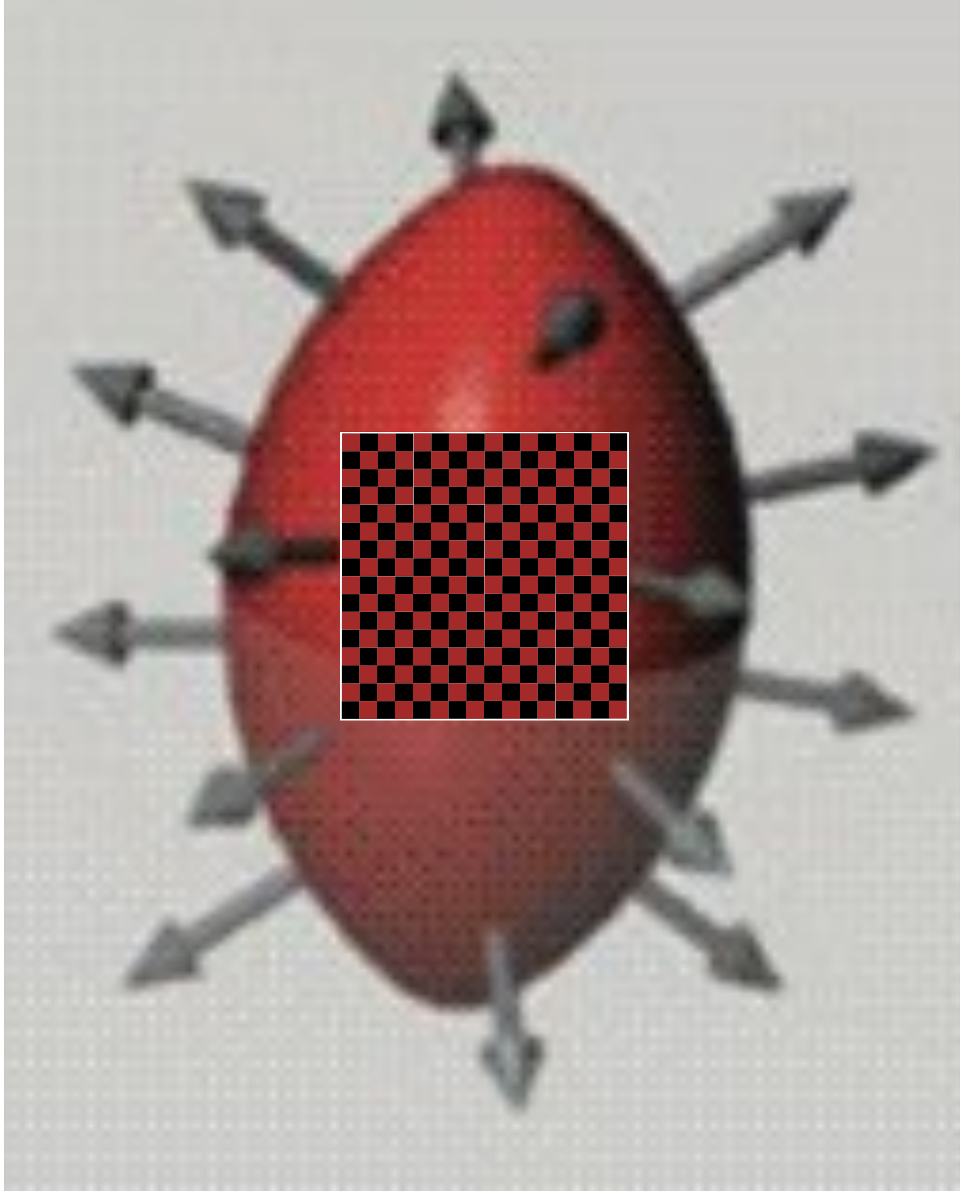
Elementary particles

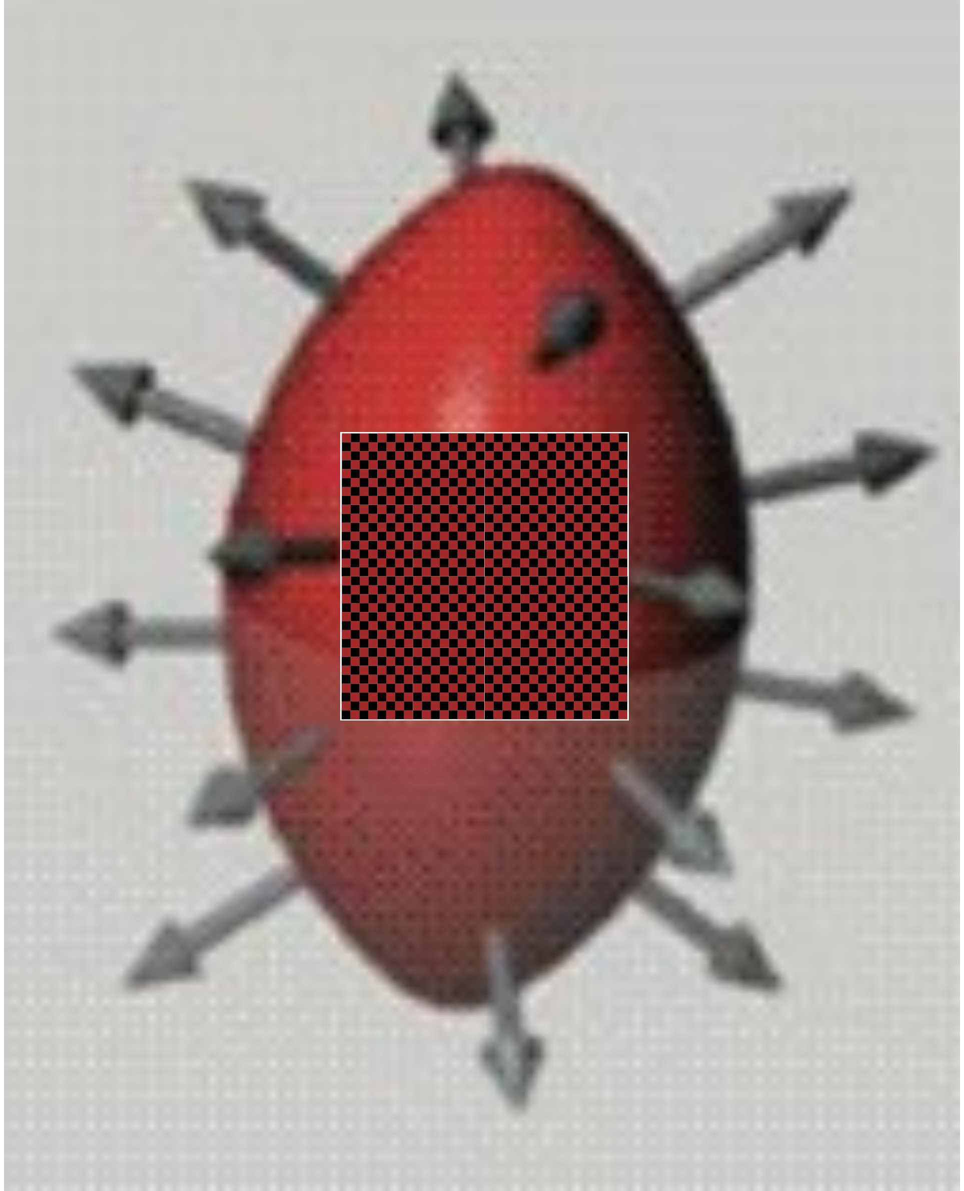


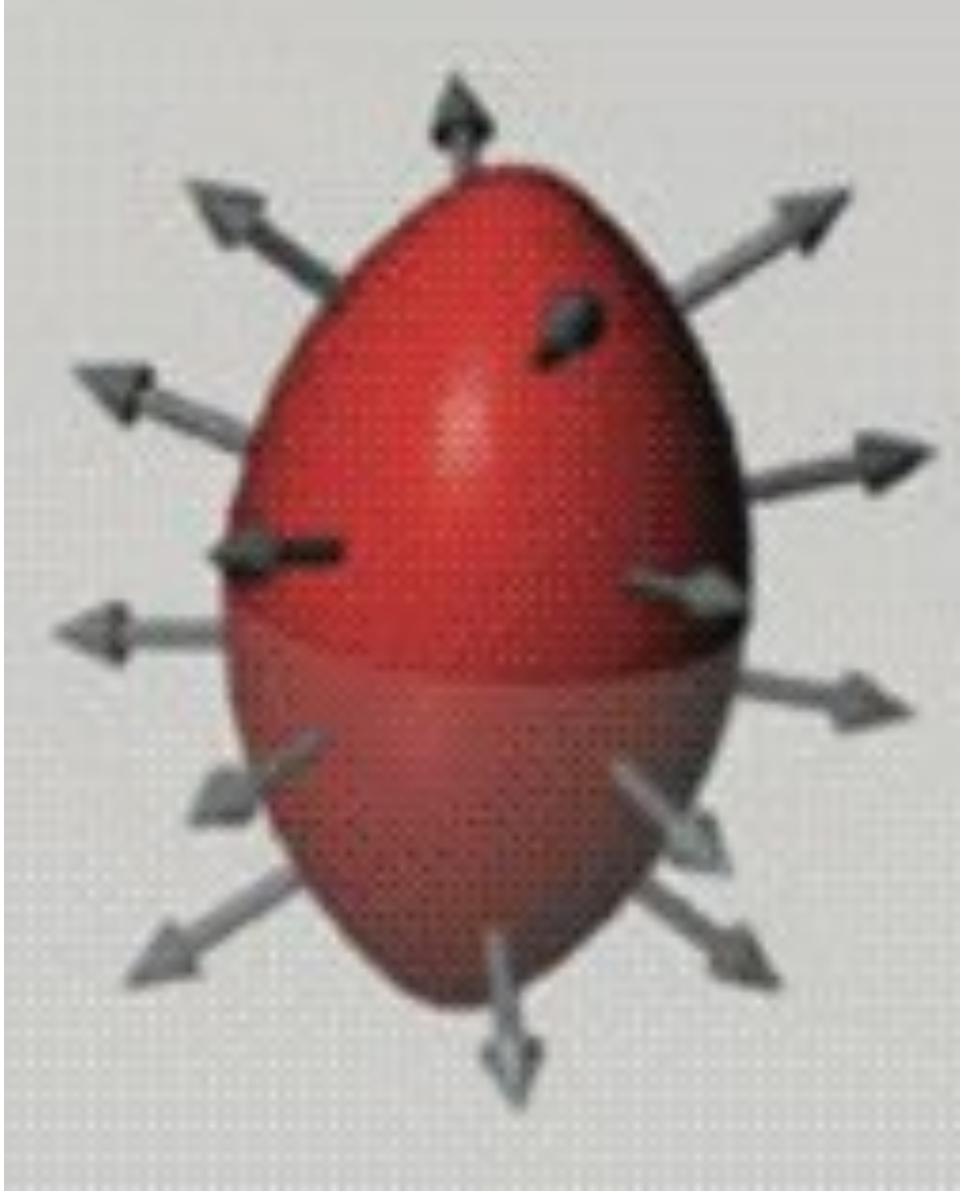
“Lattice”









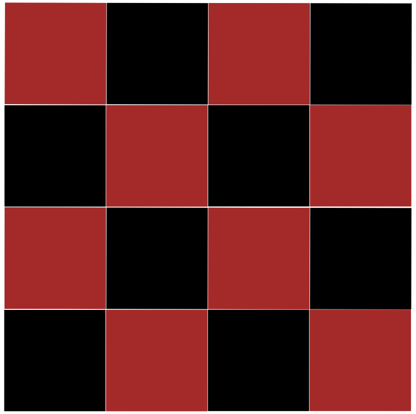


Gives us a way to learn about this system

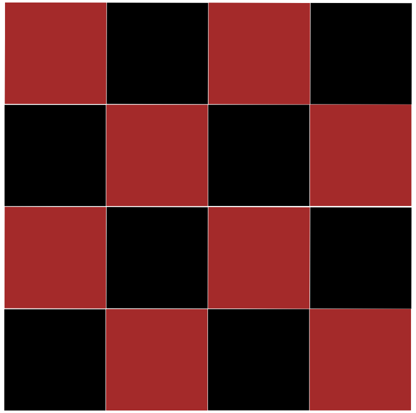
- Compare to other theory
- Maybe no other option

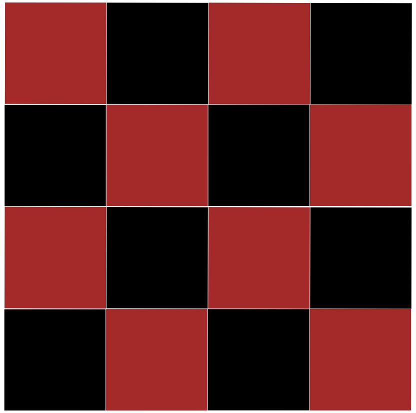
Quantum Mechanics: Fields fundamentally random

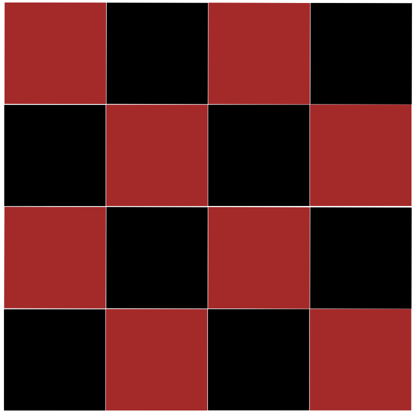
- So we can't calculate experiment outcomes
- But we **can** calculate average
- Correspondingly, lattice is **possible** outcome
- And we must calculate average



$$\langle E \rangle \approx \frac{1}{N_{lattice}} \left(E_1 + E_2 + E_3 + E_4 + \dots \right)$$







... make $N_{lattice}$

$$N_{lattice} \sim 10^6$$

What competencies? Some combination of the following:

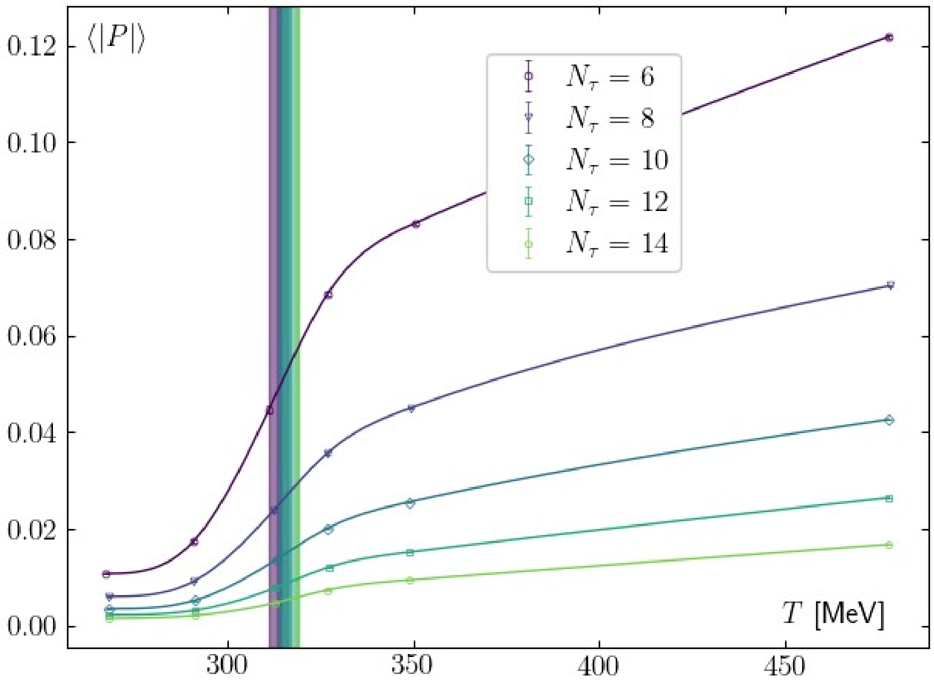
- Very **modest familiarity with advanced undergraduate physics** and math
  - Quantum physics, special relativity
  - Group theory, matrices
- **Heuristic understanding of lattice QCD** and selected topics from modern physics
  - Quantum fields
  - Strong force and confinement
  - How does a computer work?
- **Python** and **Bash** scripting
- Familiary with **Vim, VSCode**
- Using **ChatGPT** to help solve coding problems
- Basic (some intermediate) **statistics**

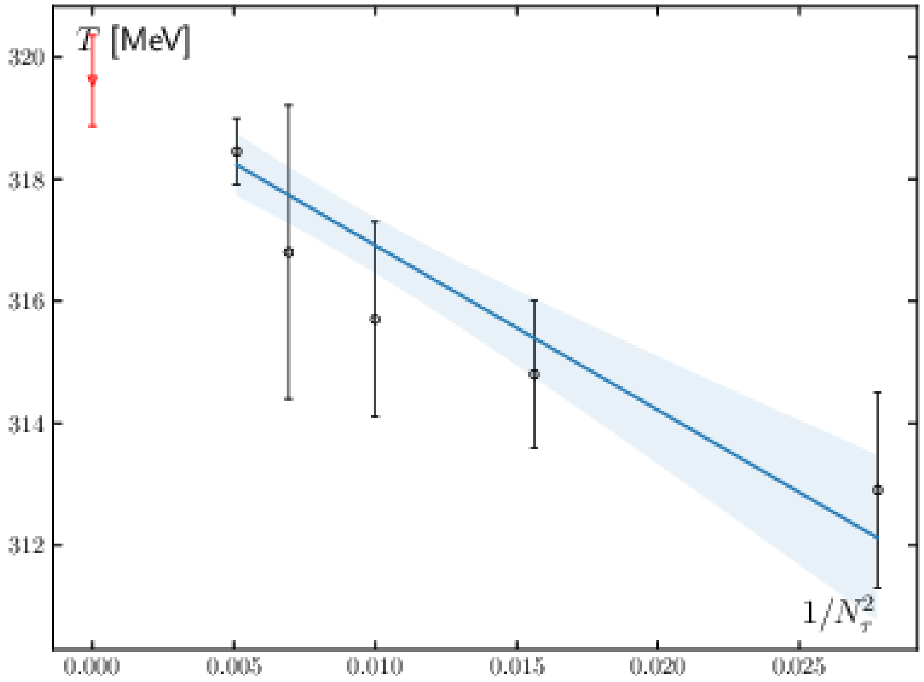
Hence, what do they do?

- **Readings** from my notes
- Compile and run SIMULATeQCD on their local machine
- Use Bash and Slurm to **manage simulations on supercomputer** (Utah's CHPC)
- Use Bash to collect and organize simulation results
- Use Python and LatticeToolbox to carry out **data analysis**
- **Encourage** them to modify public-facing LatticeToolbox
- **Report** on what they find:
  - Gave each student a topic to research and discuss
  - I did a couple topics too
  - Collect them in a pseudopaper

Tangible Results?

Help students reproduce pure SU(N) **deconfinement temperature** within 2%





Some Student Reflections:

- "The most **transferable skill** of the SRI experience that I learned was working effectively in the **linux** terminal and with **vim**."
- "The writing of the final report forced me to do some **independent study** that allowed me to **learn more about lattice QCD**."
- "This project helped me **understand just how important statistics is to modern physics** and to research in general… **I will say that I still don't know what SU(3) or Markov Chain Monte-carlo means.**"
- "I learned more about how to **read and digest more academic materials** and readings, and **how to search out information.** I personally appreciated learning more about computational tools such as using **UNIX** more frequently and **better coding practices.**"

Summary:

- 1st and 2nd year students **can** participate in lattice QCD
- Pick up proficiencies in **Python** and **statistics**
- They **get really excited** about modern physics
- They estimated hadron melting temperature, **were impressed with themselves**
- I need to improve how I convey background information

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