Lattice-QCD 🤝 Software 🤝 Hardware

Joshua Lin
Lattice-QCD group ∈ CTP

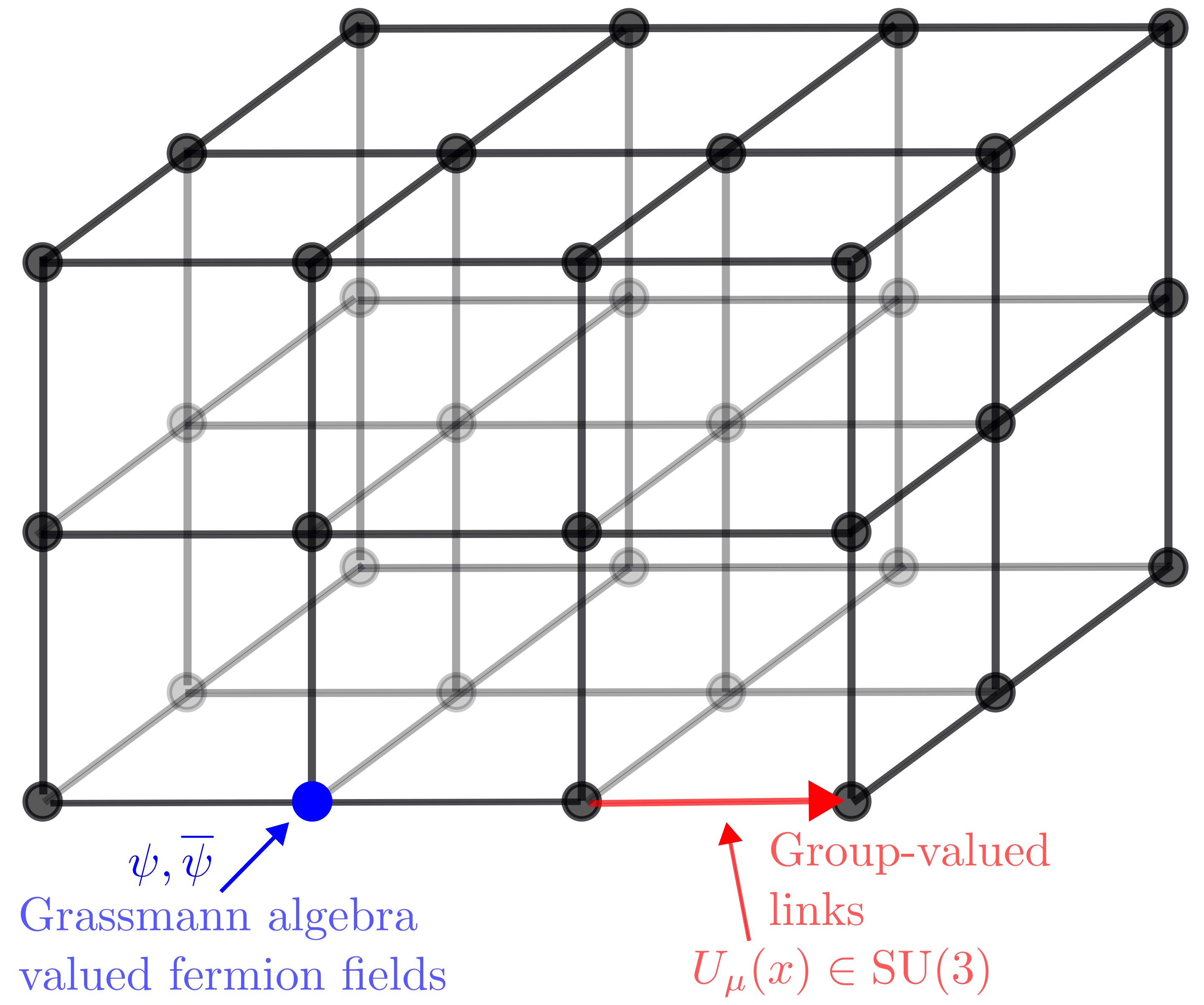
1. What is Lattice-QCD?
2. How is Lattice-QCD performed? (standard computations)
3. Overview of some Lattice QCD 🤝 Submit Cluster projects

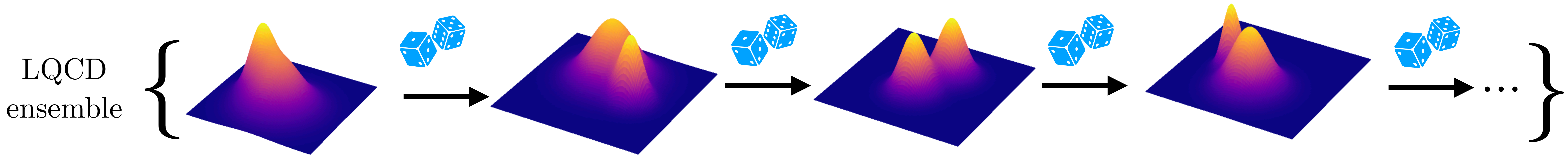
What is: Lattice-QCD

Main Idea of Lattice-QCD: "Just do the path integral" (by Monte Carlo)

$$\langle \overline{\psi}(x_1)\cdots\overline{\psi}(x_n)\psi(y_1)\cdots\psi(y_n)\rangle = \int \mathscr{D}A\mathscr{D}\overline{\psi}\mathscr{D}\psi\ \overline{\psi}(x_1)\cdots\overline{\psi}(x_n)\psi(y_1)\cdots\psi(y_n)\ e^{-S[U,\overline{\psi},\psi]}$$

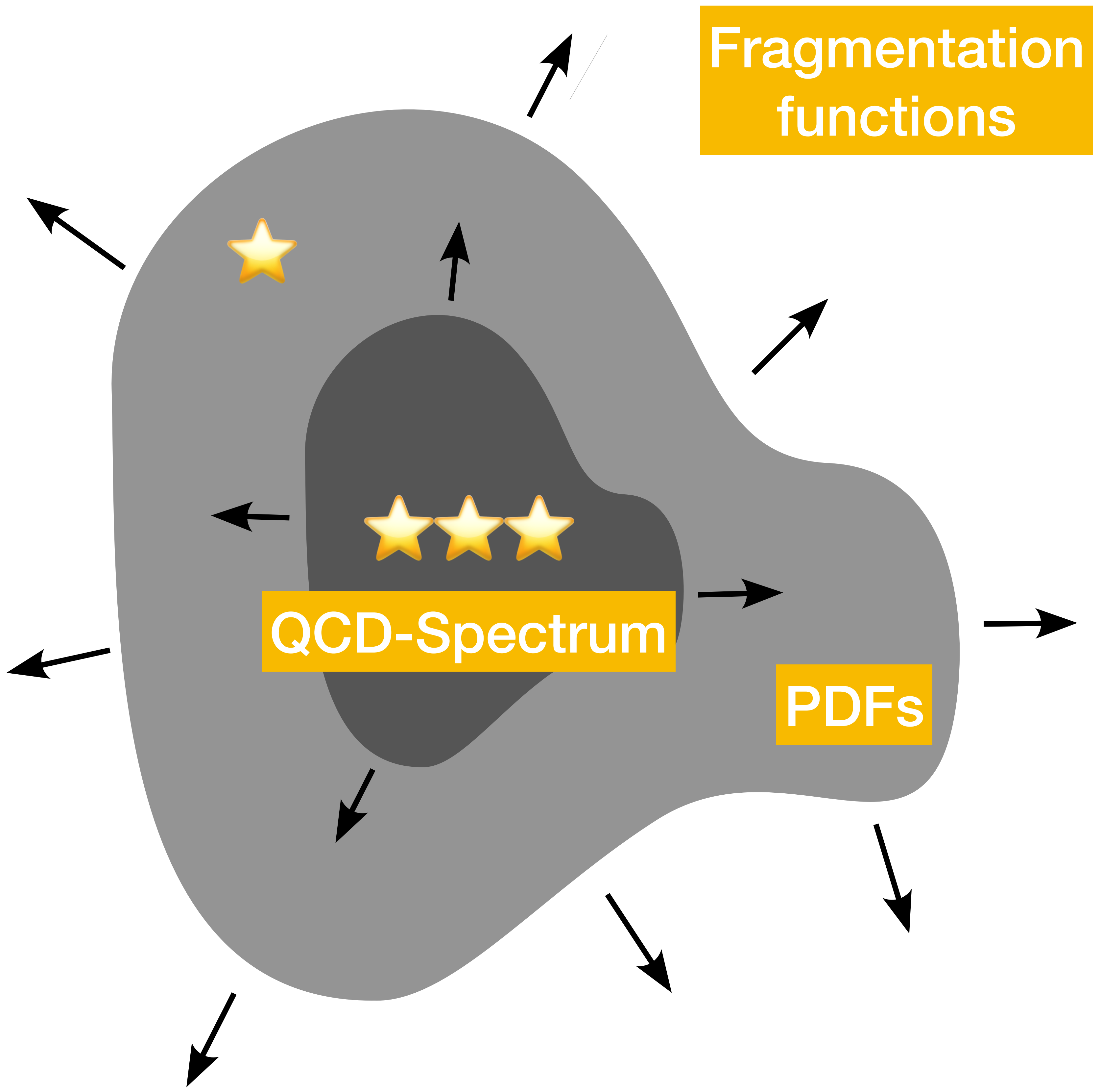
$$\langle \mathcal{O}_1(x_1)\cdots\mathcal{O}_n(x_n)\rangle = \int DU\ \det[D^{ab}_{\alpha\beta}(x,y)]^{n_f}\ e^{-S_{\text{gauge}}[U]}\ \mathcal{O}_1(x_1)\cdots\mathcal{O}_n(x_n)$$





Generate an Ensemble → Measure Correlation Functions → Perform Fits

Progress in Lattice-QCD



Space of all observables

Progress in Lattice-QCD falls into a few categories:

- Computers get faster, allowing for more precise measurements of physical quantities.
- Develop new techniques for measuring things we already knew how to measure, *better* or *faster*
- Develop techniques to measure *previously unmeasurable* quantities.

How is: Lattice-QCD done

- Algorithms are well-documented, standardised*...
- There are a few packages that really dominate the market:

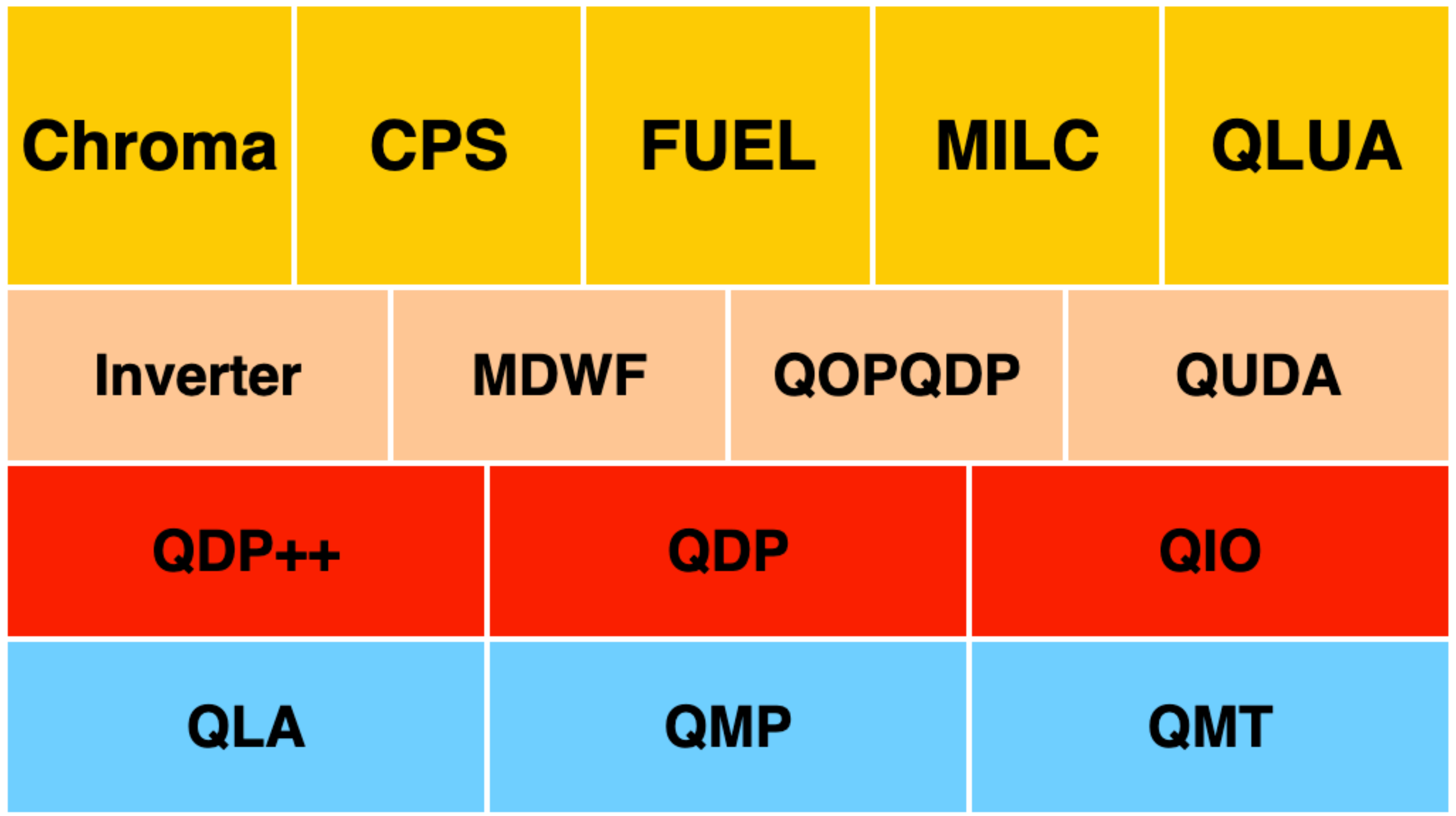
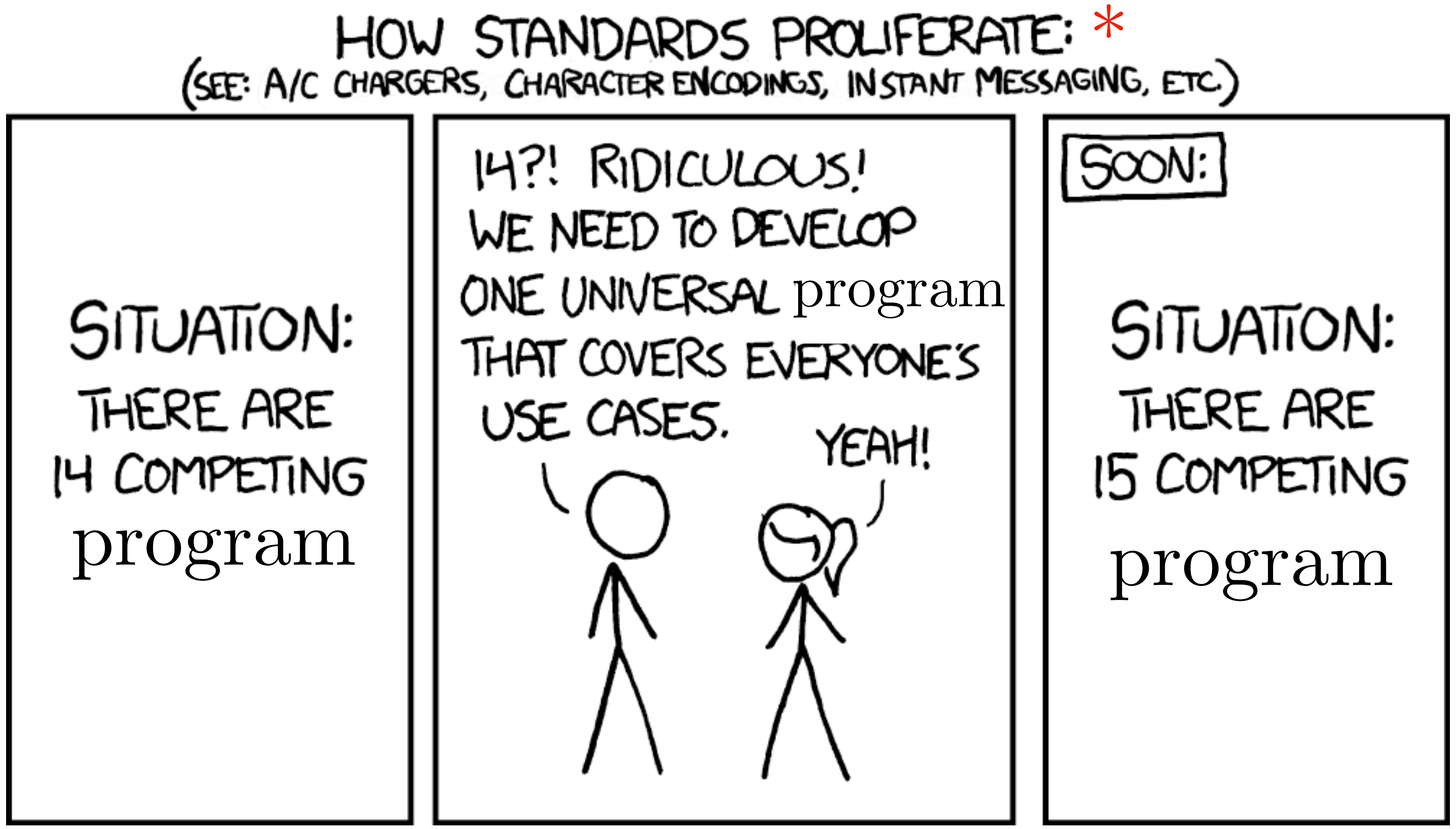


Figure 1: The SciDAC Layers and the software module architecture.

+Grid/GPT, LatticeQCD.jl, <u>SIMULATeQCD</u> ,“jaxlat”(working name), others...

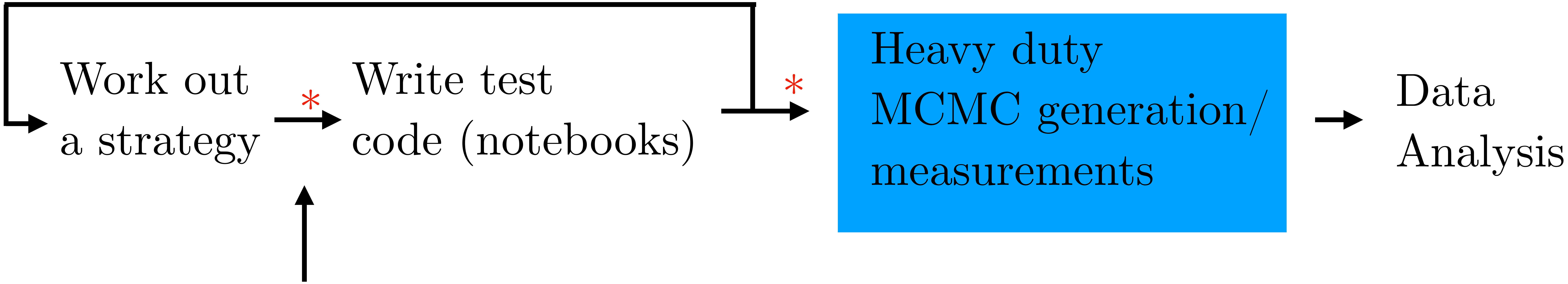


It is empowering to be able to write all code from ground up

Goal : Do cool science

"Problem": spend time stuck in the weeds dealing with writing build scripts, reproducible environments, compilation errors, ...

(my) Workflow for standard calculations



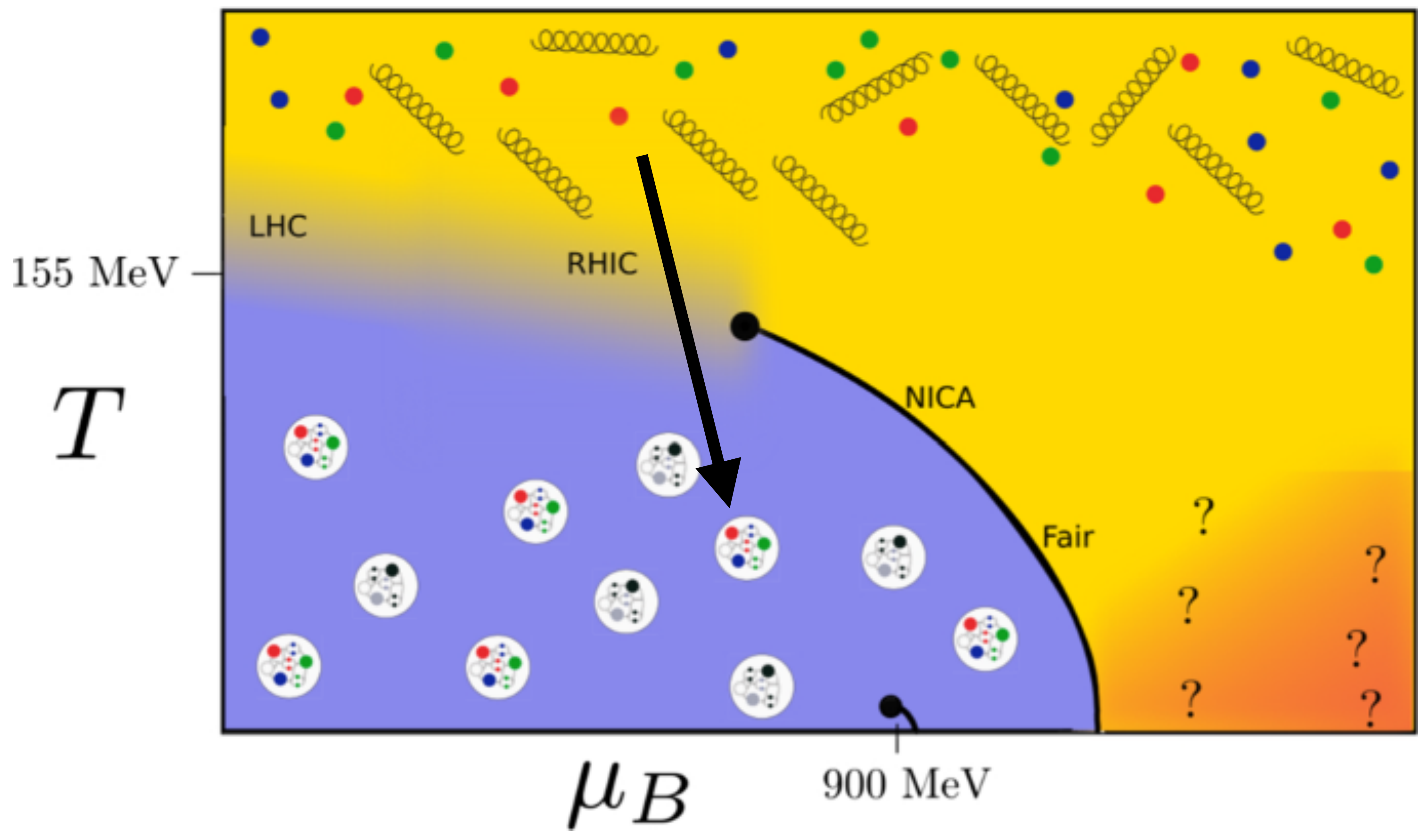
Containers
ease this
pain point

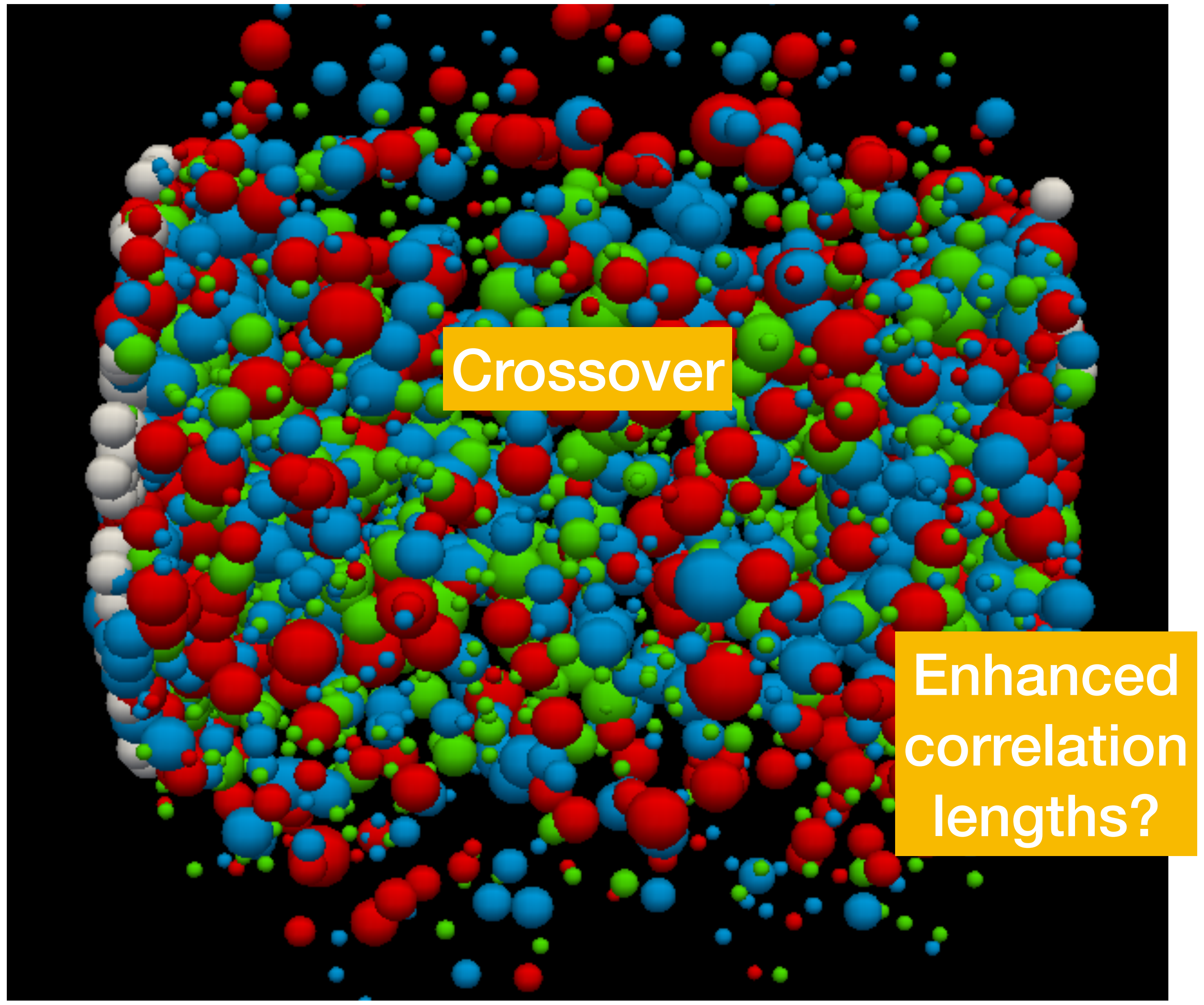
(I appreciate the singularity support!)

```
singularity exec --bind /data docker://gptdev/shell python3 ...
```

Project 1 : “The Edge of the Fireball”

(Boundary criticality of Quantum Yang Mills)

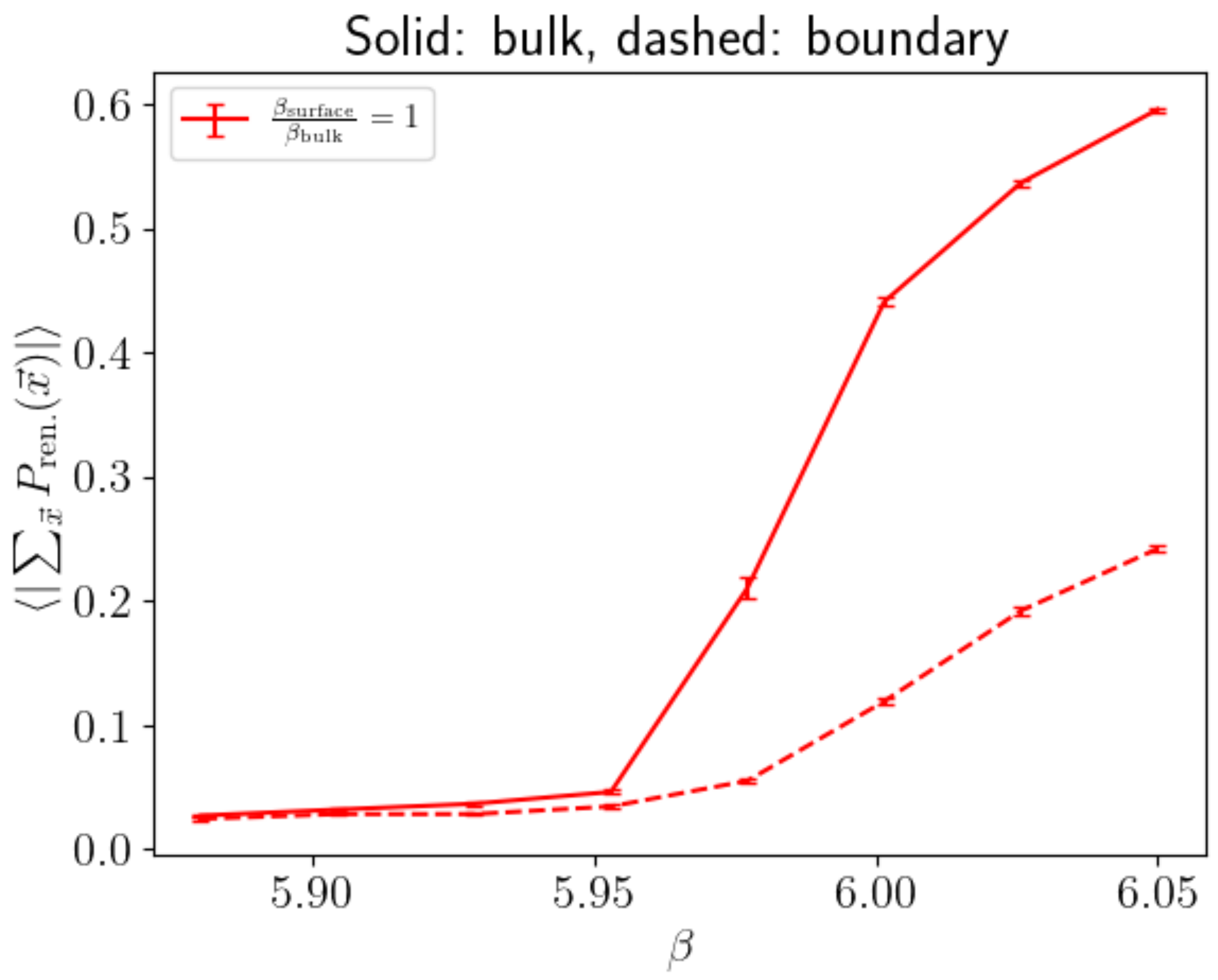


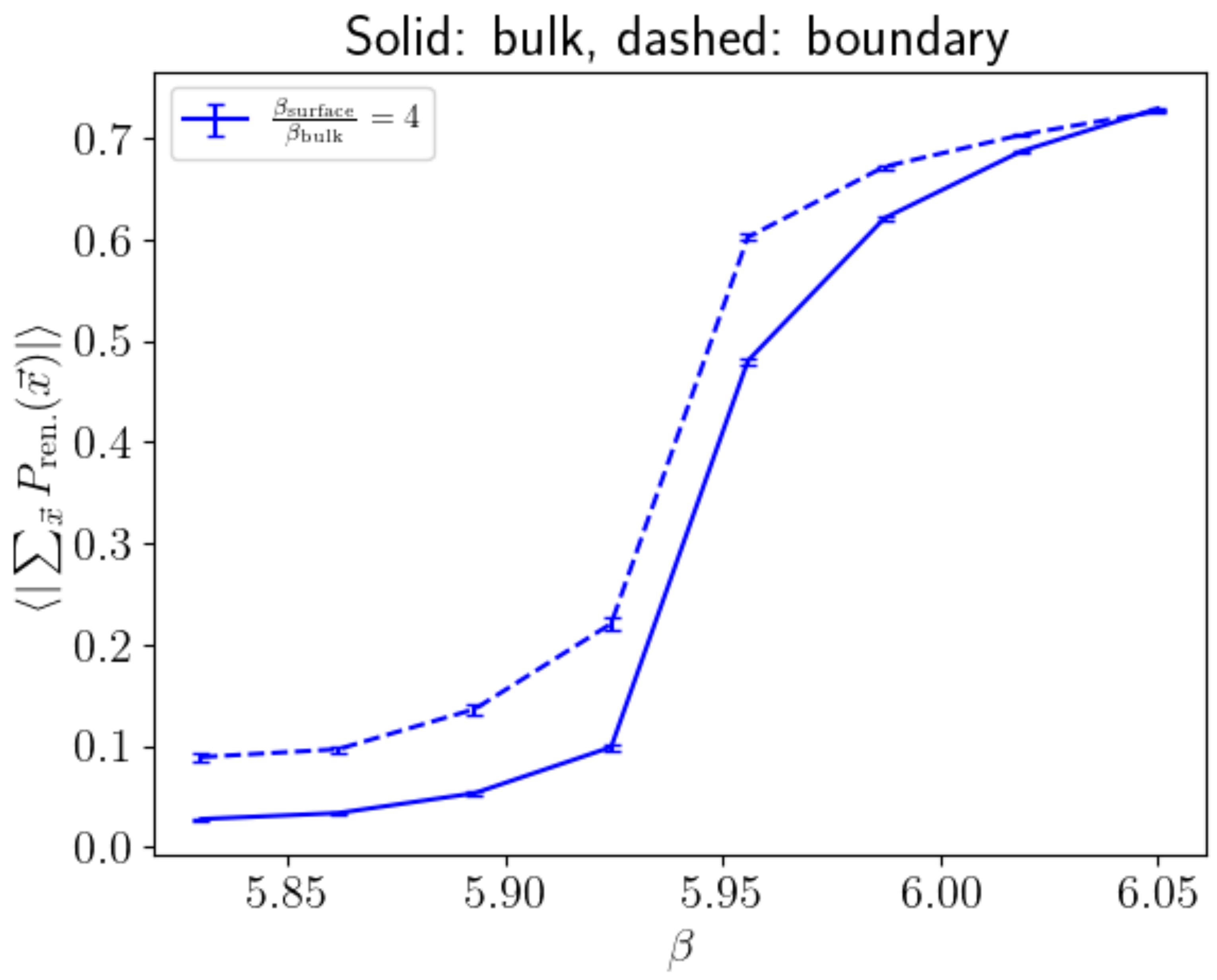


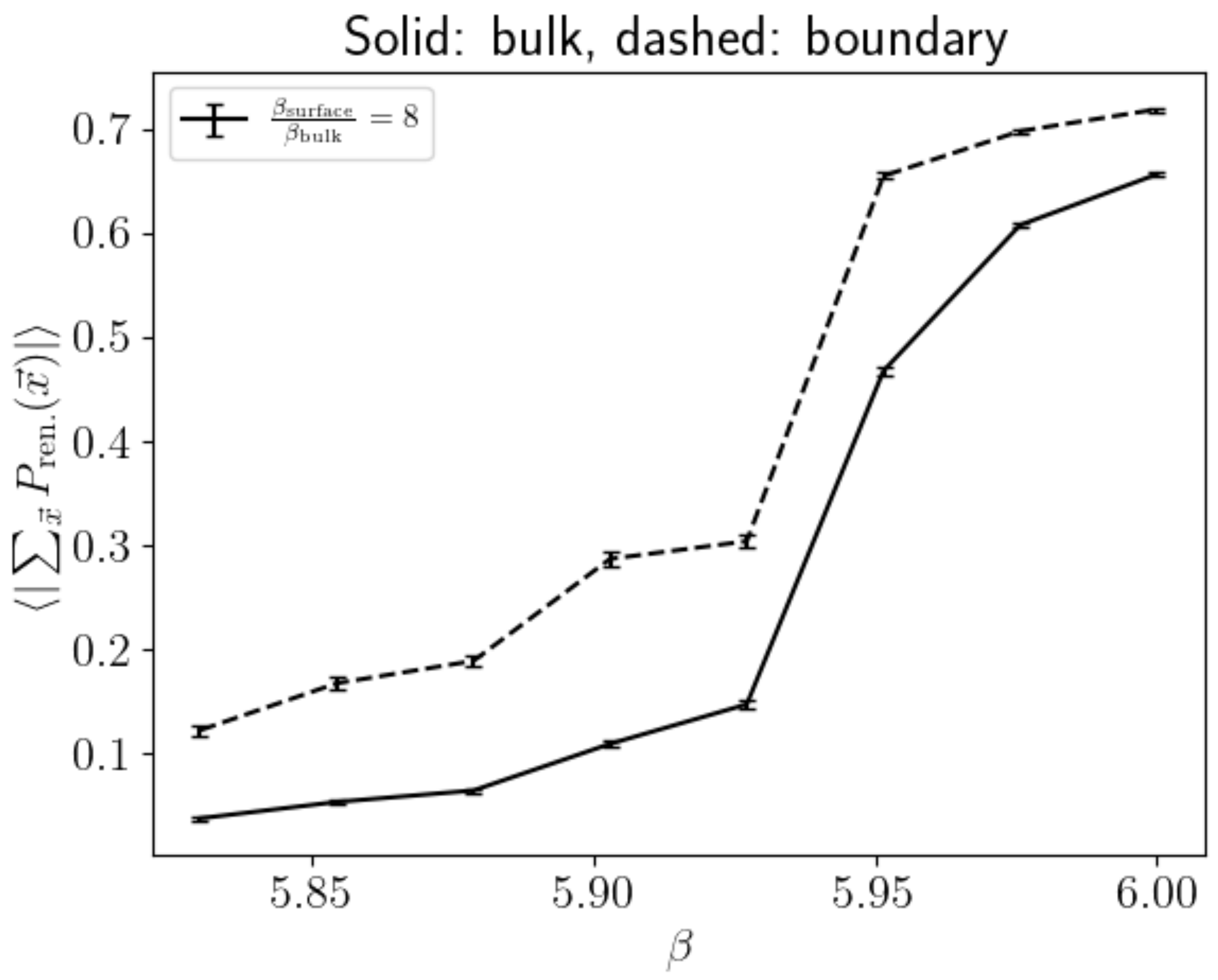
Project 1 : "The Edge of the Fireball"

(Boundary criticality of Quantum Yang Mills)

(mostly motivated by Max Metlitski's physics colloquium 11/21/2024)

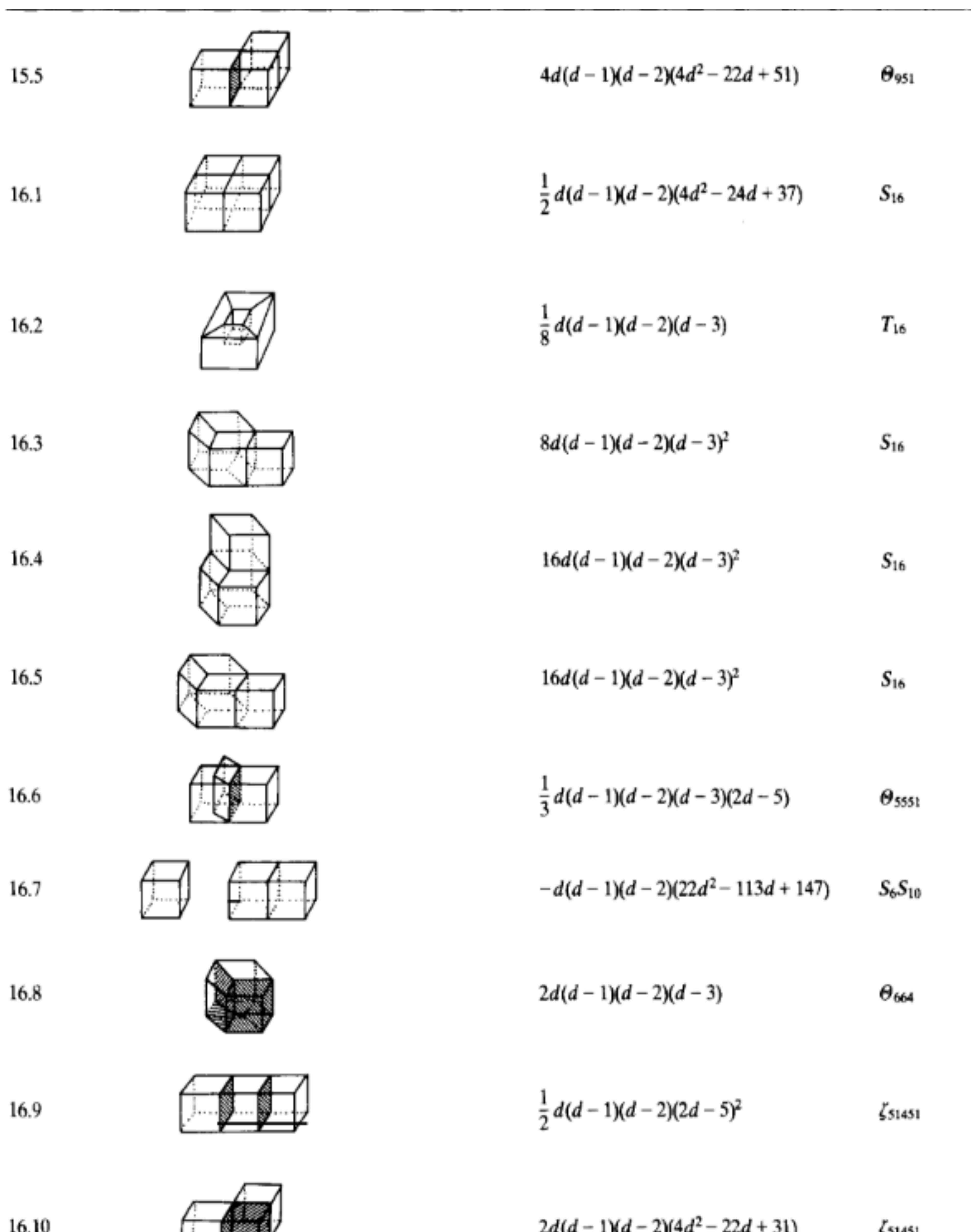






Project 2 : Strong Coupling Expansions

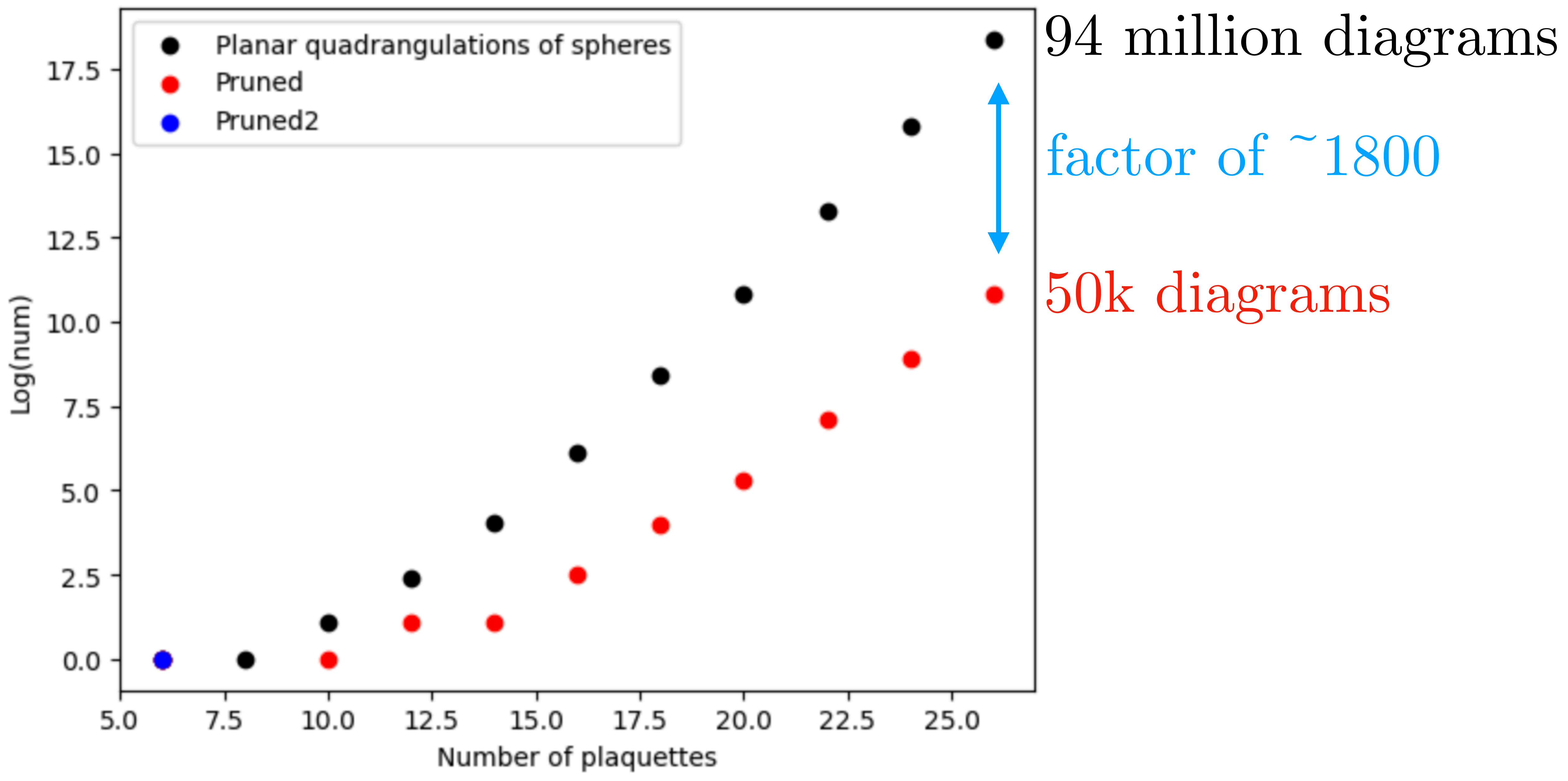
- Idea : do perturbation theory in $\frac{1}{\alpha_{S,\mathrm{QCD}}}$
- In condensed-matter setups, these expansions are usually known as `High-temperature expansions'
- Works incredibly well for certain systems, can we get it to work well for QCD?
- People tried in the 80s, but ran into a few problems:
  - It's hard to enumerate diagrams by hand (they got it wrong in a couple places)
  - roughening transitions

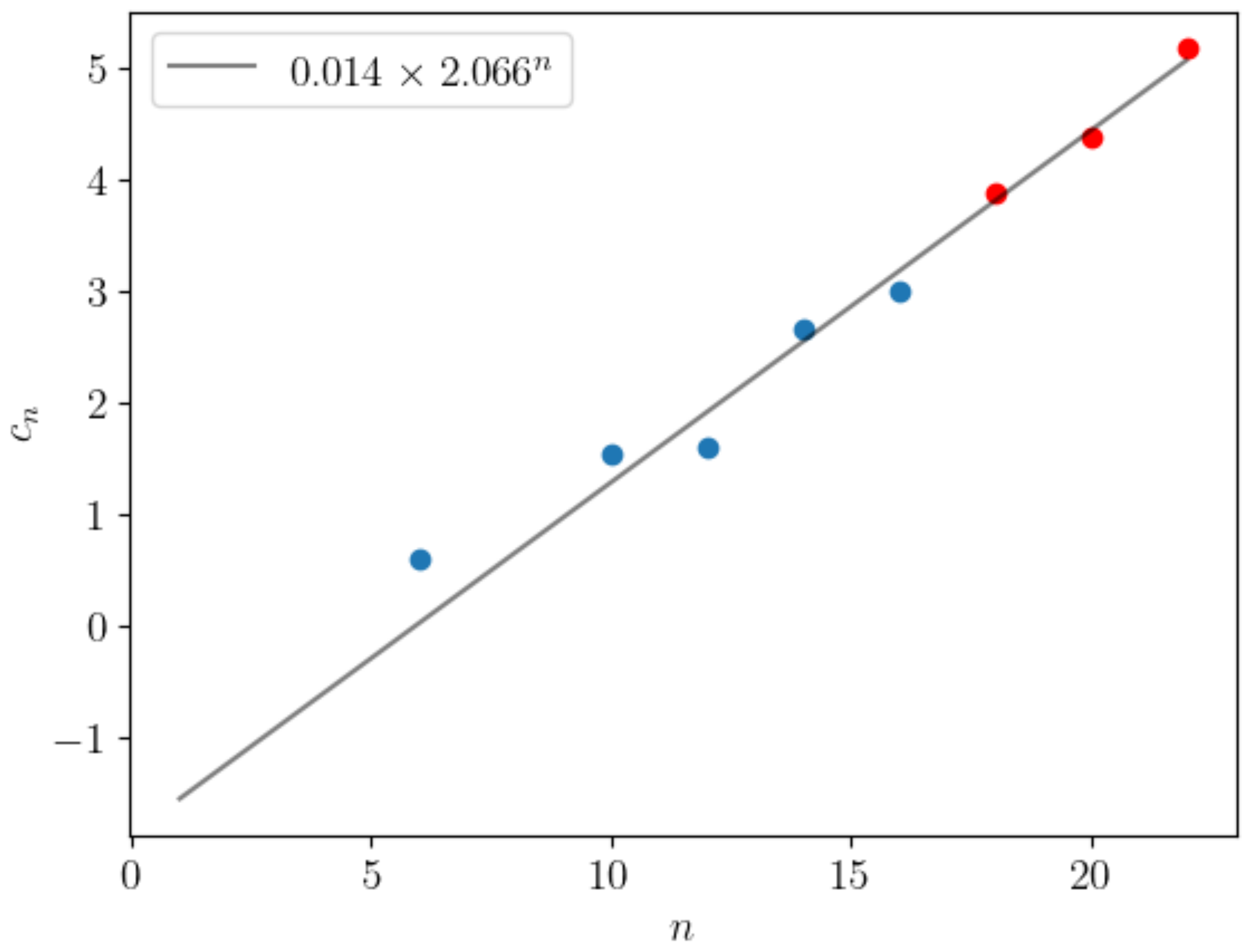


15.5	$4d(d-1)(d-2)(4d^2-22d+51)$	θ_{951}
16.1	$\frac{1}{2}d(d-1)(d-2)(4d^2-24d+37)$	S_{16}
16.2	$\frac{1}{8}d(d-1)(d-2)(d-3)$	T_{16}
16.3	$8d(d-1)(d-2)(d-3)^2$	S_{16}
16.4	$16d(d-1)(d-2)(d-3)^2$	S_{16}
16.5	$16d(d-1)(d-2)(d-3)^2$	S_{16}
16.6	$\frac{1}{3}d(d-1)(d-2)(d-3)(2d-5)$	θ_{5551}
16.7	$-d(d-1)(d-2)(22d^2-113d+147)$	S_6S_{10}
16.8	$2d(d-1)(d-2)(d-3)$	θ_{664}
16.9	$\frac{1}{2}d(d-1)(d-2)(2d-5)^2$	ζ_{51451}
16.10	$2d(d-1)(d-2)(4d^2-22d+31)$	[illegible]

- Improved algorithms allow us to prune many diagrams that give 0 contribution

- We can generate new coefficients (letting us probe the roughening transition to greater precision)





Thank You!