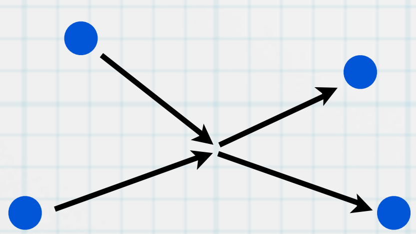
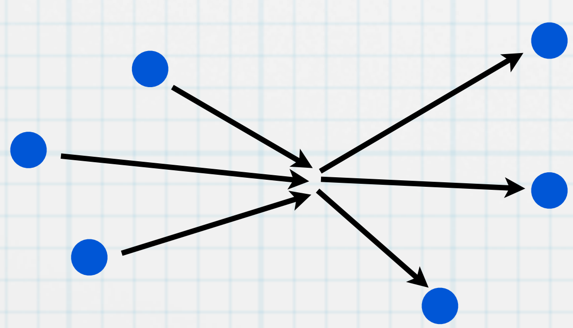
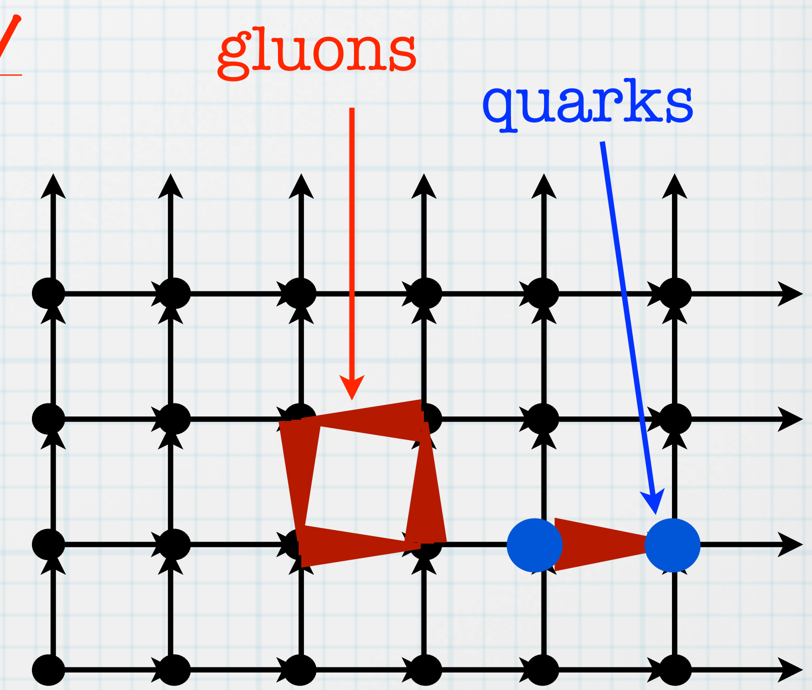
Using Lattice QCD to search for physics beyond the standard model

Steve Sharpe

http://faculty.washington.edu/srsharpe/







Particle, Strings & Fields

aka Particle Theory

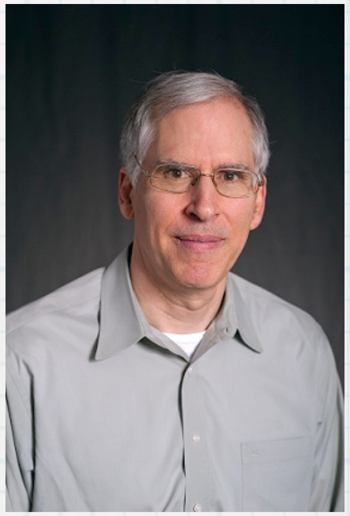
http://www.phys.washington.edu/groups/ptuw/index.html

Steve Ellis
(Emeritus)

Andreas Karch

Ann Nelson

Steve Sharpe



Laurence Yaffe

Graduate Students

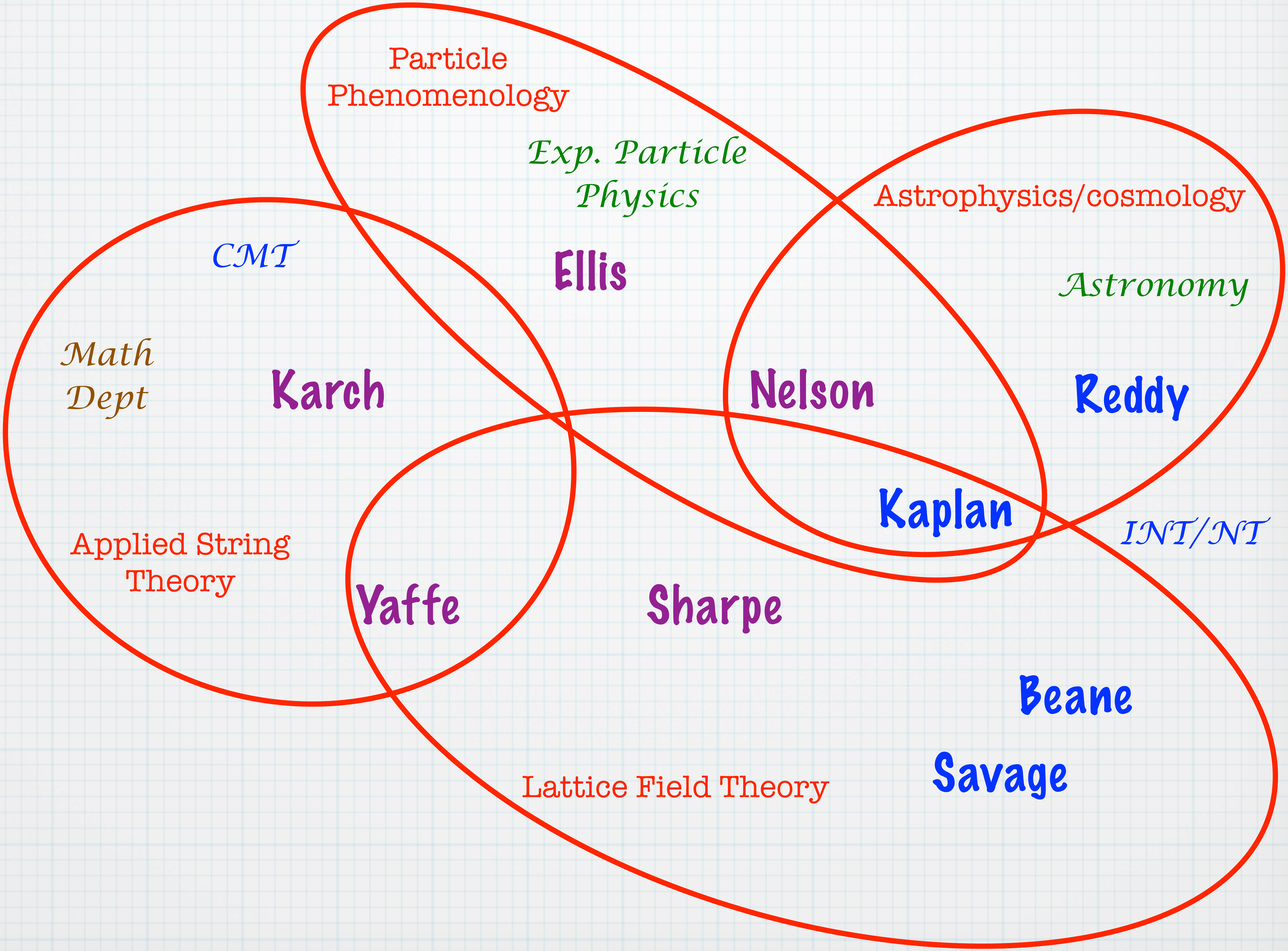
* Mackenzie Barton-Rowledge (Nelson/Sanjay Reddy): neutron stars
* John Fuini (Yaffe): studying quark-gluon plasma using "applied string theory"
* Akshay Ghalsasi (Nelson): cosmological applications of particle theory
* Kira Hicks (Nelson): (just starting)
* Derek Horkel (Sharpe): effective field theory applied to lattice QCD, ...
* Brandon Robinson (Karch): applied string theory=holography, wormholes





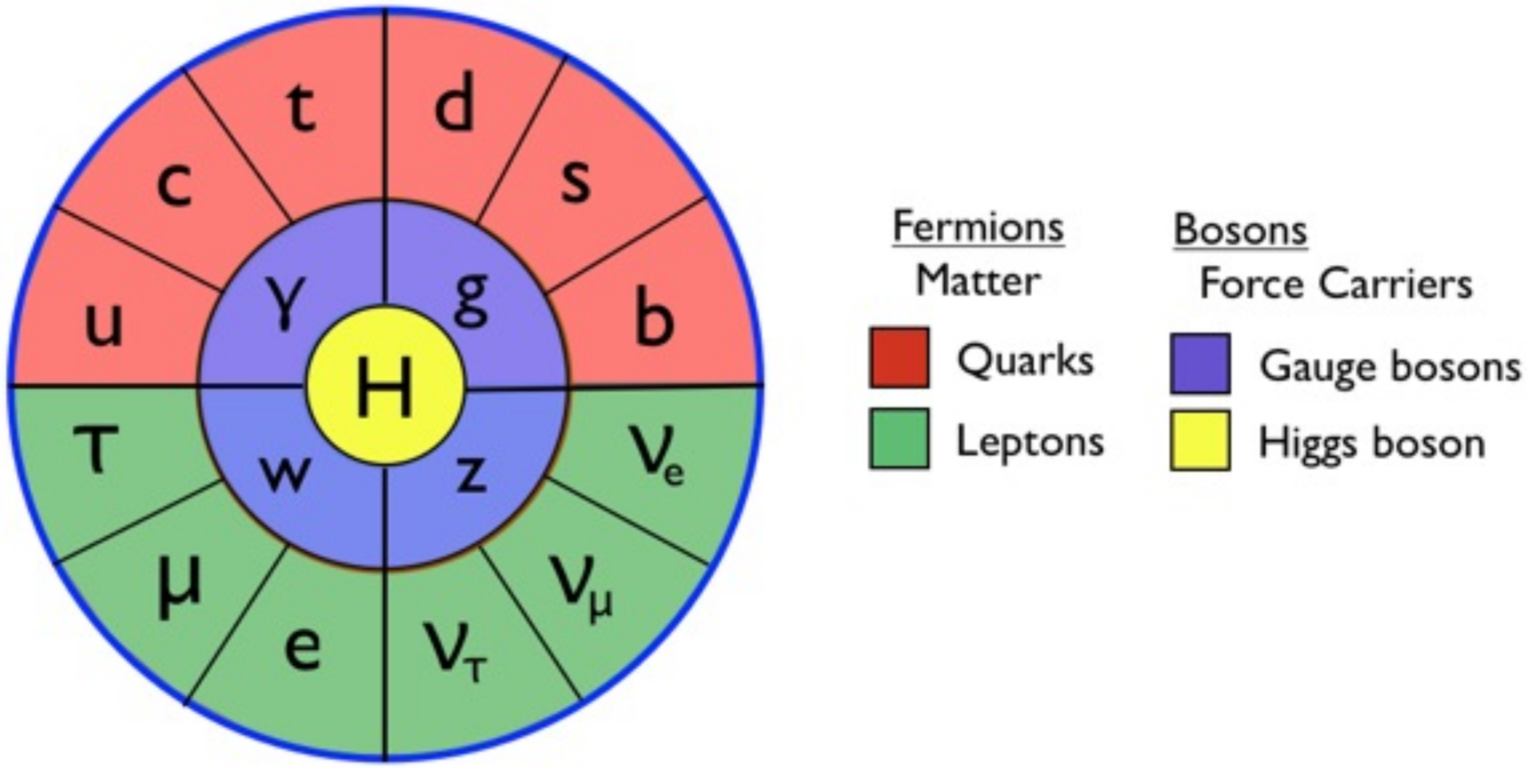

Postdocs

* David McKeen: Beyond the Standard Model Phenomenology & Cosmology
* Christoph Uhlemann: string theory, holography



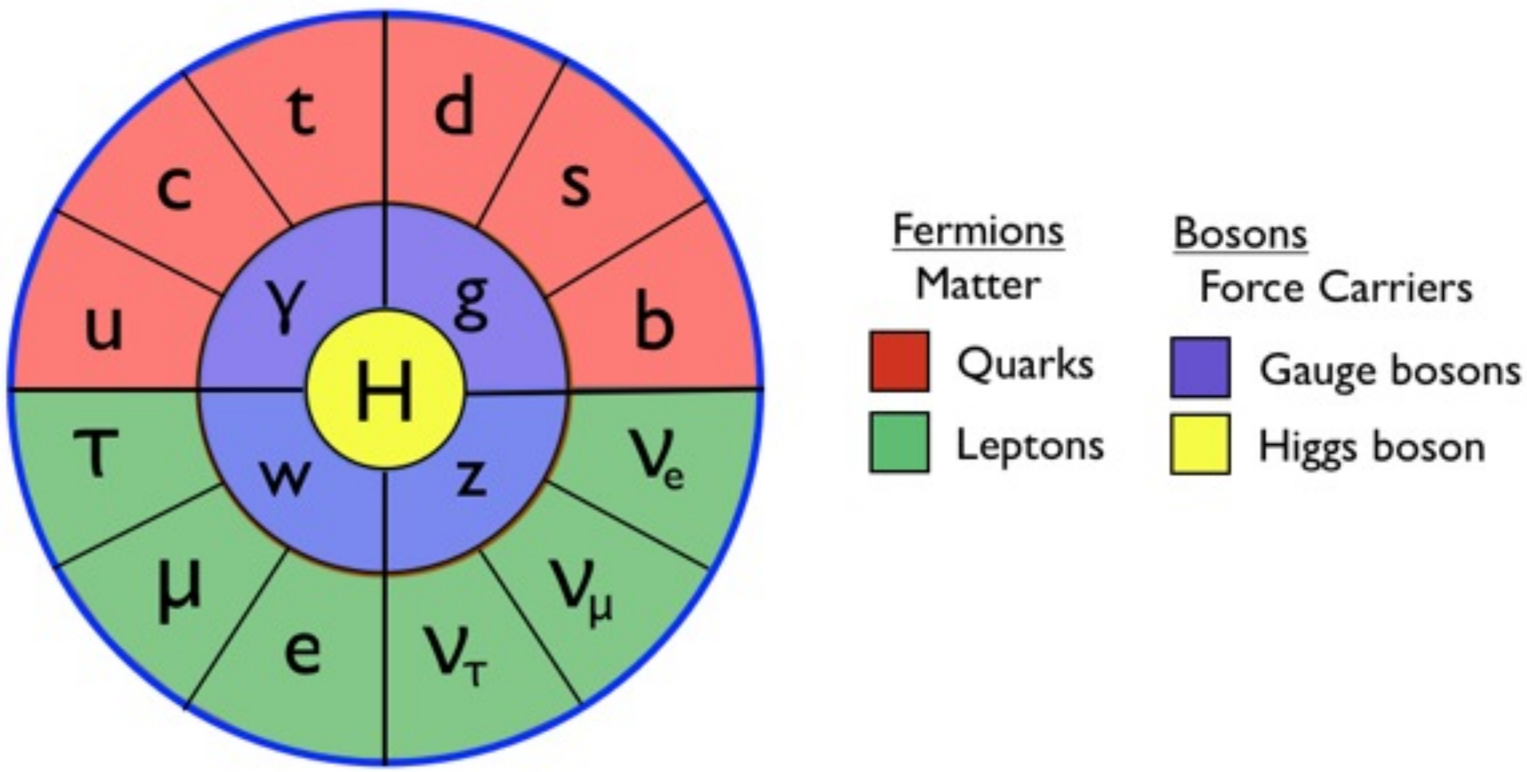
Particle
Phenomenology
Exp. Particle
Physics
Astrophysics/cosmology
CMT
Ellis
Astronomy
Math
Dept
Karch
Nelson
Reddy
Kaplan
INT/NT
Applied String
Theory
Yaffe
Sharpe
Beane
Savage
Lattice Field Theory

Standard model is successful …



Particles of the Standard Model (a quantum field theory)

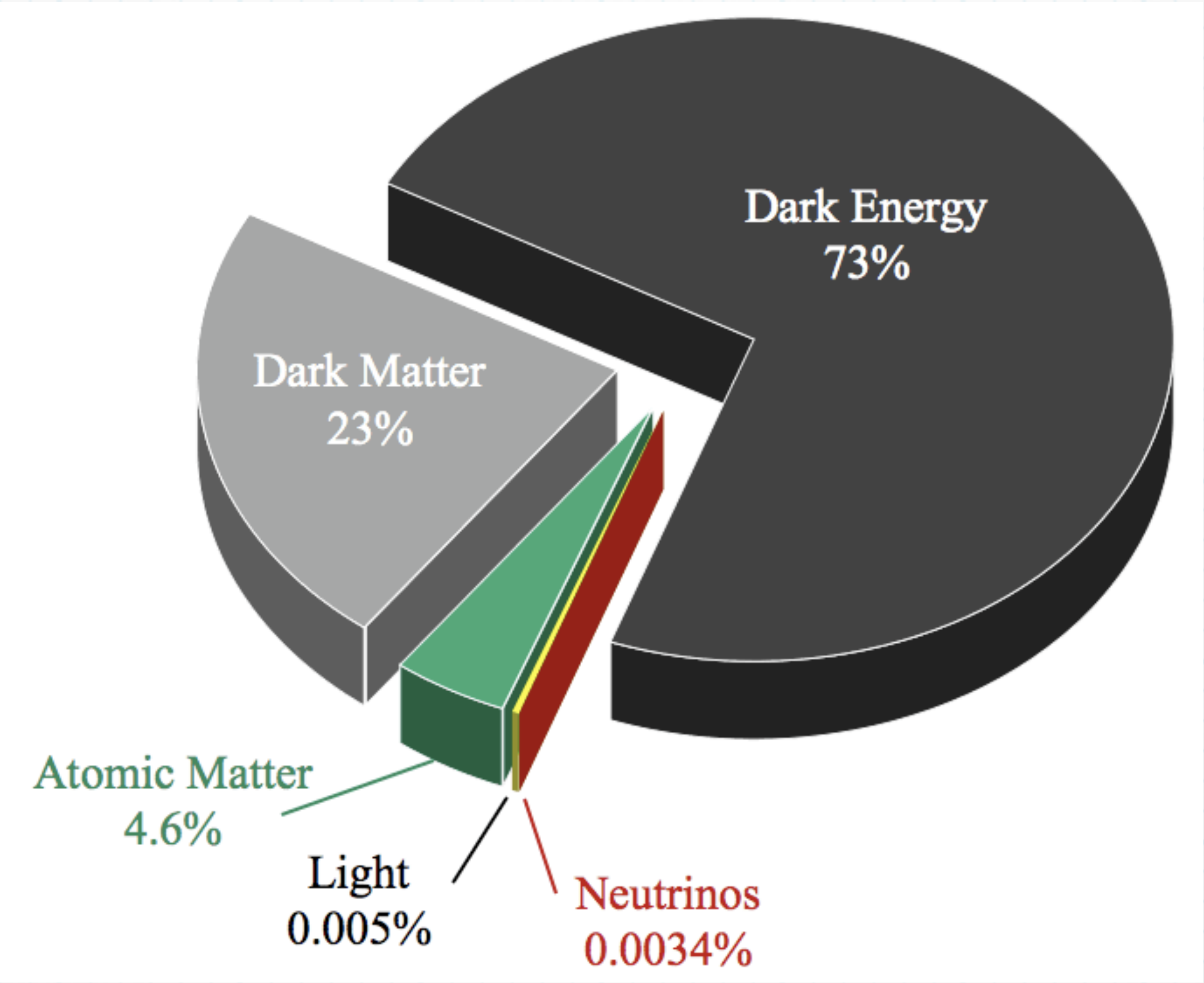
... but many questions remain



Particles of the Standard Model (a quantum field theory)

- ✦Why the pattern of masses & mixings?
- ✦What lies beyond the SM, at the TeV+ scale?
- ✦How can gravity & QM be combined?

...particularly in cosmology

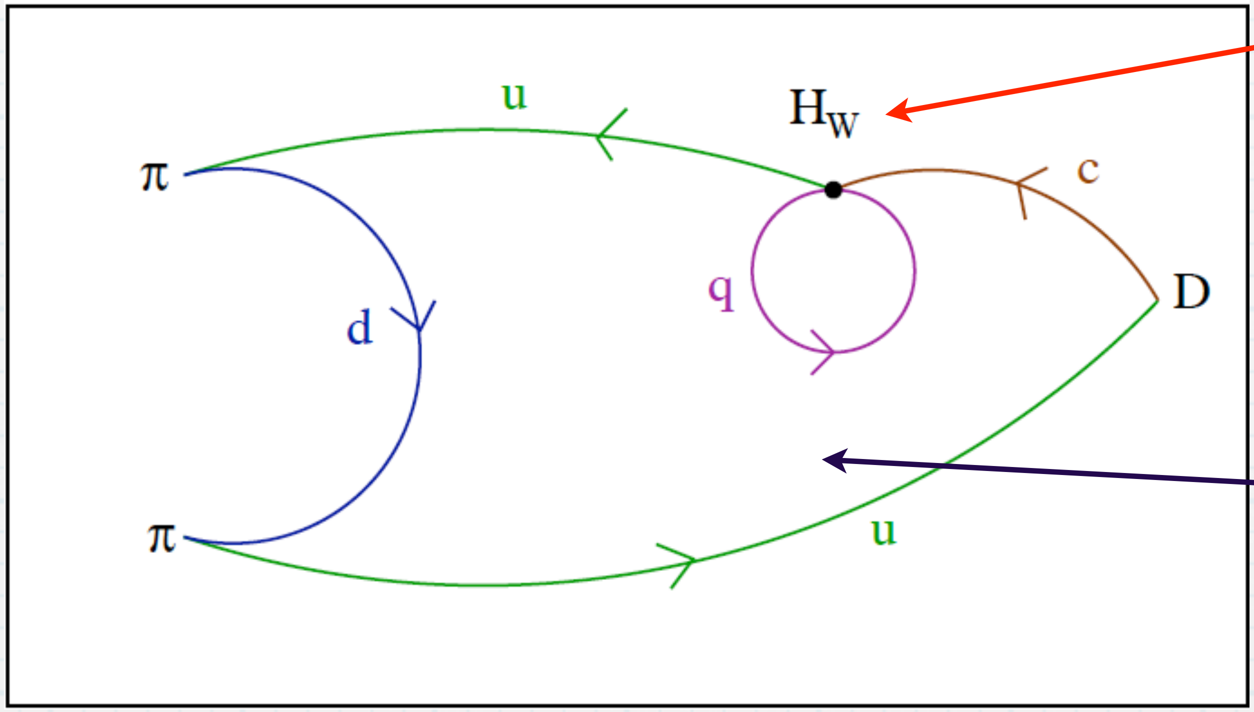


- ✦What are dark matter & dark energy?
- ✦What is the mechanism of baryogenesis (which requires new sources of CP violation)?

Bottom-up approach

- ✦Search for new physics by looking for small deviations from the Standard Model
- ✦E.g. CP violation in $D \to \pi\pi$

CP-violation enters here due to virtual t and c quarks

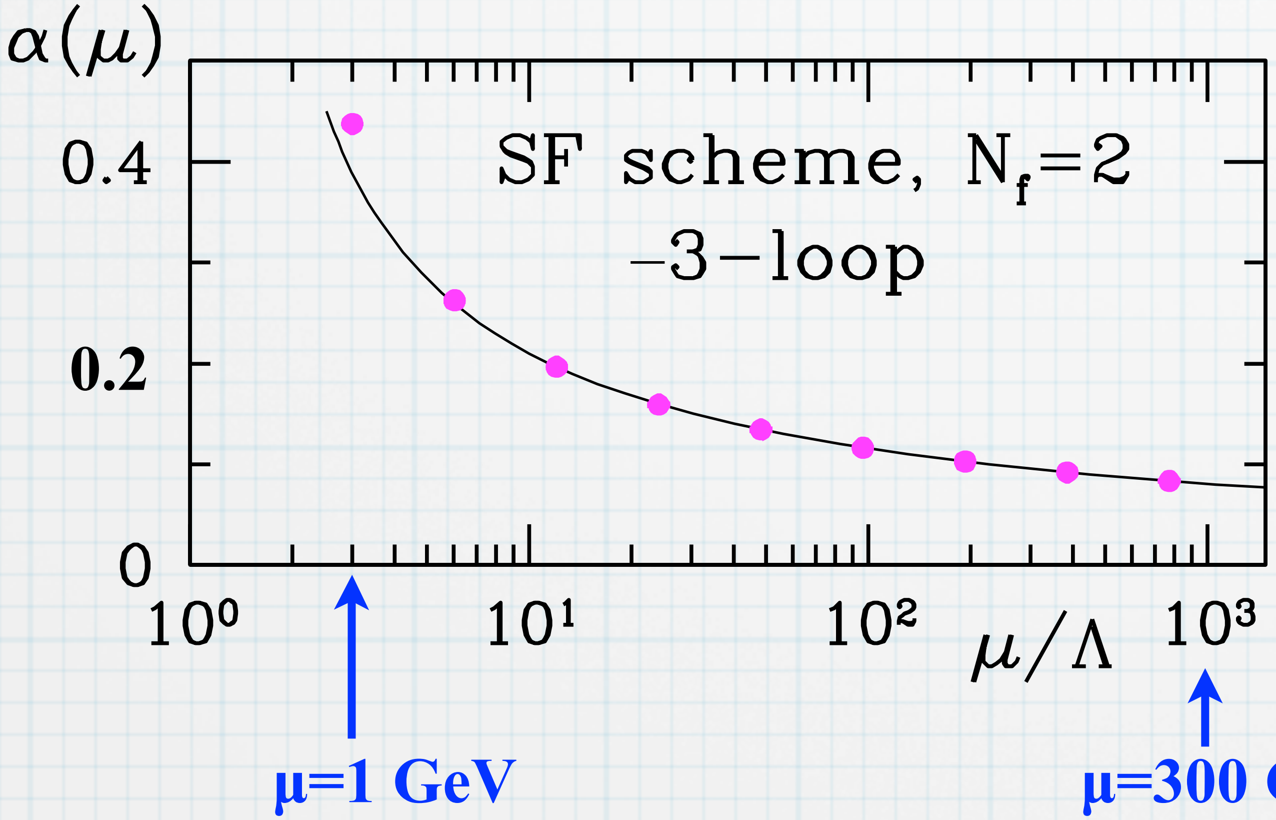


gluons & q-qbar pairs live here

Does experiment (future LHCb) agree with SM prediction (future lattice QCD)?

Theorist's task

✦ Understand & calculate properties of strongly coupled theories, e.g. QCD



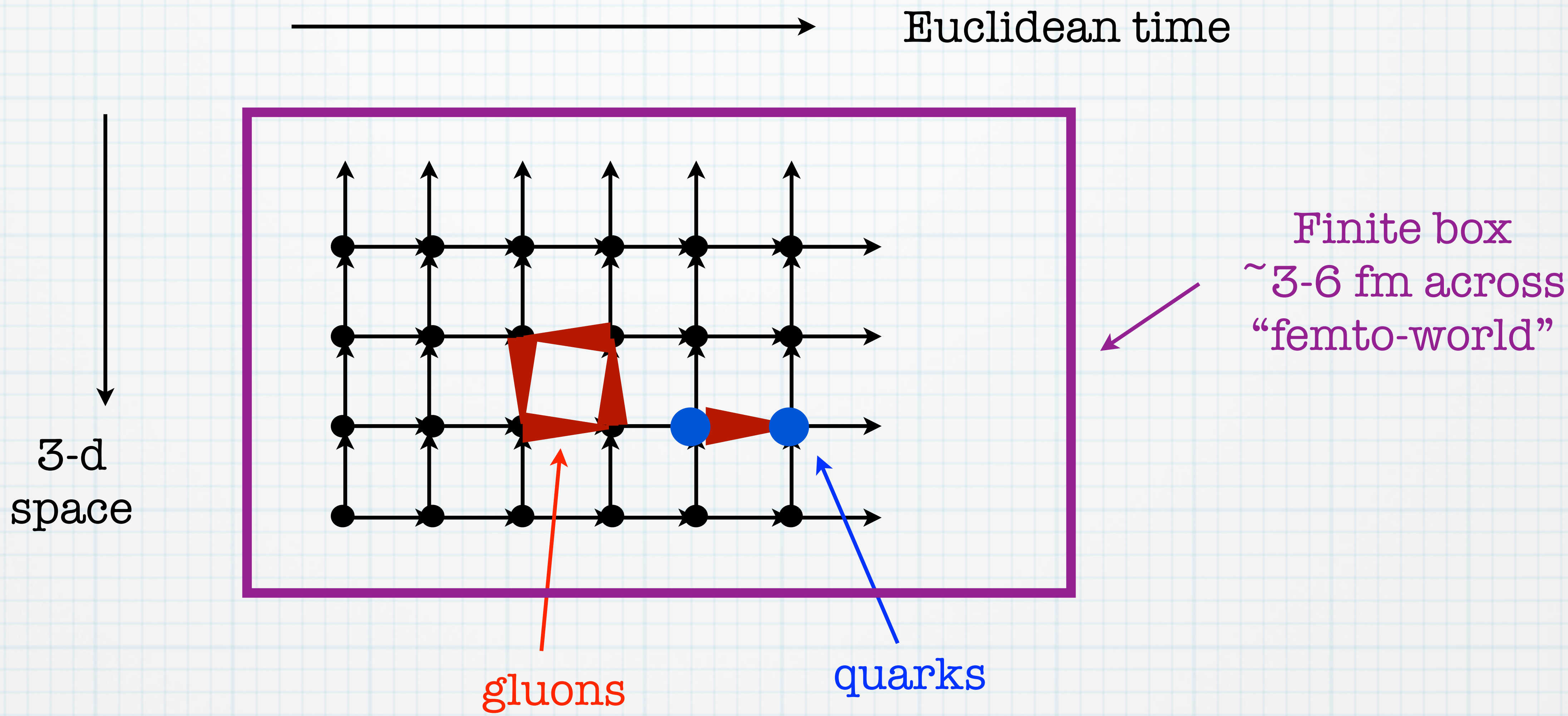
ALPHA collaboration

Perturbation theory fails at strong coupling

Quarks confined in hadrons

quark & gluon jets

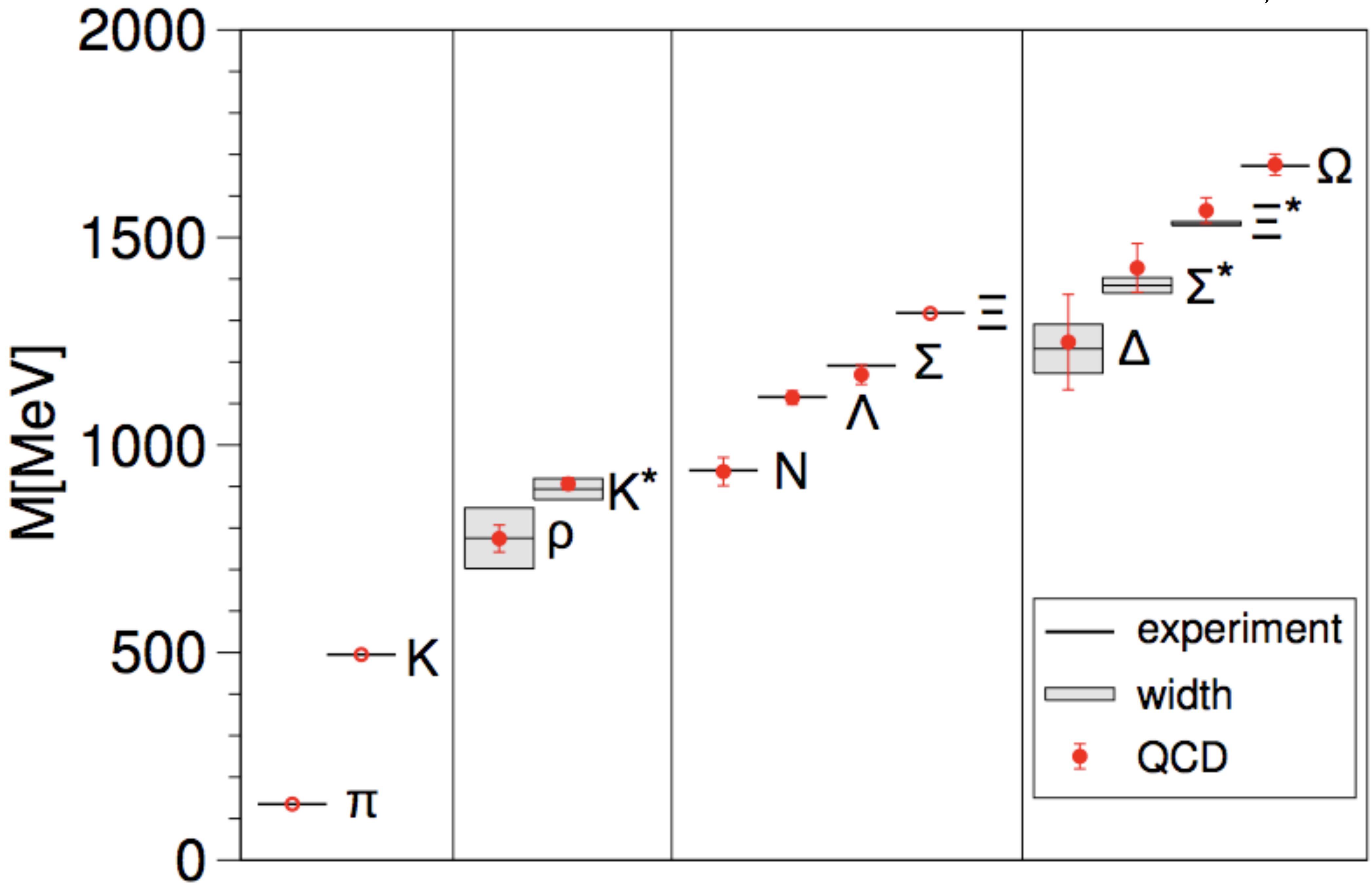
Only first-principles method: Lattice QCD



- Use Feynman path integral implemented by Monte-Carlo
- Requires supercomputers and a lot of auxiliary QFT calculations
- My present focus: developing finite-volume QFT tools for extracting multiparticle decays, e.g. $D \to \pi\pi$, 4π, KK, $\eta\eta$, ...

Postdiction: hadron spectrum

BMW Collaboration, 2008

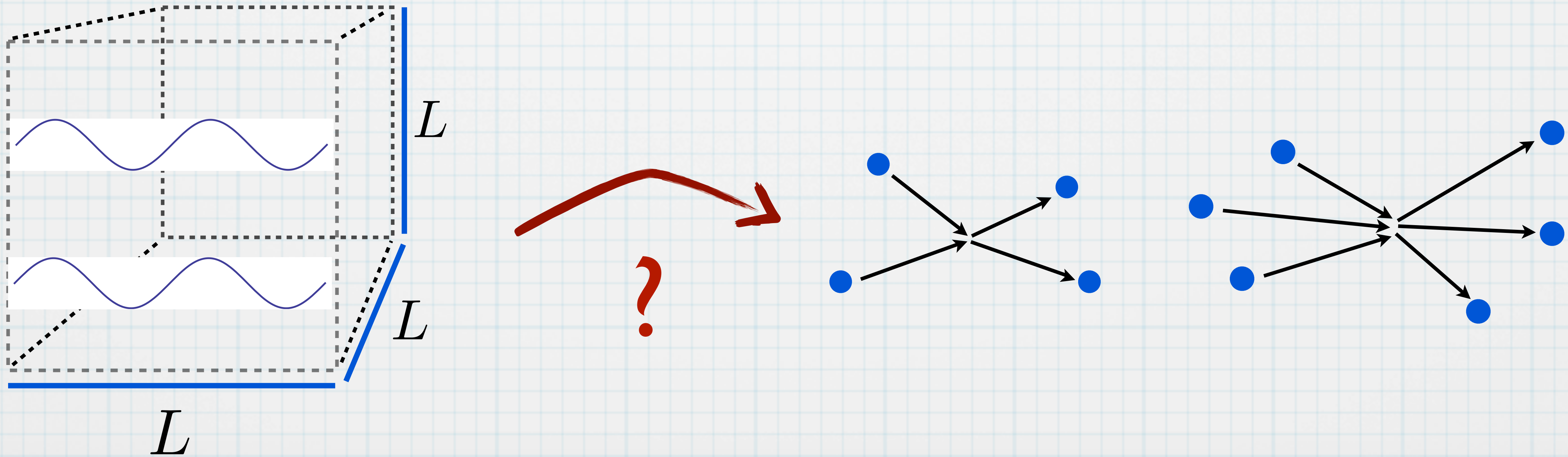


Lattice QCD results have ~percent accuracy, and reproduce experimentally measured spectrum (and many other quantities)

Example of my present research

Ongoing projects with ex-student Max Hansen & others

* How can we calculate three (or more) particle interactions and decay rates ($K \rightarrow 3\pi$) using LQCD?
* LQCD can calculate numerically energies of multiple particles in a finite box (3-6fm across!), but how do we go from these results to scattering amplitudes?
* This is a finite-volume QFT problem



Example of my present research

- Long solved for 2 particles, and now used in practice
- We solved for 3 identical spinless particles

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Relativistic, model-independent, three-particle quantization condition

Expressing the three-particle finite-volume spectrum in terms of the three-to-three scattering amplitude

Perturbative results for two and three particle threshold energies in finite volume

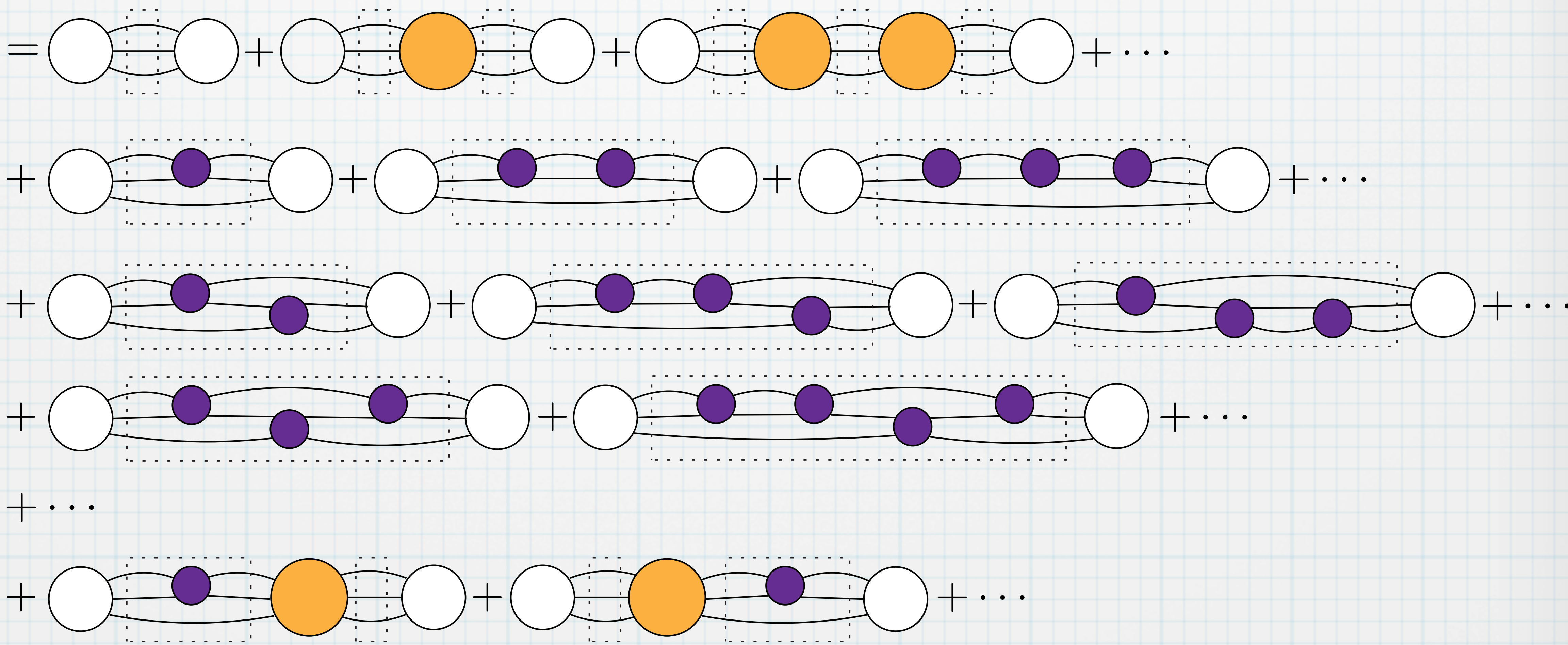
Maxwell T. Hansen* and Stephen R. Sharpe†

- Now we need to generalize, remove simplifying assumptions, and turn into a practical tool
- Numerical results are ahead of theory—much to do!

Example of my present research

- Requires all-orders analysis of finite-volume Feynman diagrams, separating off volume dependence

$C_L(E, \vec{P}) =$



Example of my present research

- Final result looks pretty simple

The finite-volume spectrum is determined by

$$\det\left[1 + F_3 \mathcal{K}_{\mathrm{df},3}\right] = 0\,, \tag{18}$$

where the determinant is over the direct product space just introduced. The matrix F_3 is

$$F_3 \equiv \frac{F}{2\omega L^3}\left[-\frac{2}{3} + \frac{1}{1 + [1 + \mathcal{K}_2 G]^{-1}\mathcal{K}_2 F}\right]\,, \tag{19}$$

where

$$\left[\frac{1}{2\omega L^3}\right]_{k',\ell',m';k,\ell,m} \equiv \delta_{k',k}\delta_{\ell',\ell}\delta_{m',m}\frac{1}{2\omega_k L^3}\,, \tag{20}$$

$$G_{p,\ell',m';k,\ell,m} \equiv \left(\frac{k^*}{q_p^*}\right)^{\ell'} \frac{4\pi Y_{\ell',m'}(\hat{k}^*)H(\vec{p}\,)H(\vec{k}\,)Y^*_{\ell,m}(\hat{p}^*)}{2\omega_{kp}(E - \omega_k - \omega_p - \omega_{kp})}\left(\frac{p^*}{q_k^*}\right)^{\ell}\frac{1}{2\omega_k L^3}\,, \tag{21}$$

$$F_{k',\ell',m';k,\ell,m} \equiv \delta_{k',k} F_{\ell',m';\ell,m}(\vec{k}\,)\,, \tag{22}$$

$$F_{\ell',m';\ell,m}(\vec{k}\,) = F^{i\epsilon}_{\ell',m';\ell,m}(\vec{k}\,) + \rho_{\ell',m';\ell,m}(\vec{k}\,)\,, \tag{23}$$

$$F^{i\epsilon}_{\ell',m';\ell,m}(\vec{k}\,) = \frac{1}{2}\left[\frac{1}{L^3}\sum_{\vec{a}} - \int_{\vec{a}}\right]\frac{4\pi Y_{\ell',m'}(\hat{a}^*)Y^*_{\ell,m}(\hat{a}^*)H(\vec{k}\,)H(\vec{a}\,)H(\vec{b}_{ka})}{2\omega_a 2\omega_{ka}(E - \omega_k - \omega_a - \omega_{ka} + i\epsilon)}\left(\frac{a^*}{q_k^*}\right)^{\ell+\ell'}\,, \tag{24}$$

A typical student timeline in PT

* Year 1: PT Journal club in spring & independent study in summer
* Year 2: Take QFT, particle physics, group theory,...; continue indep studies (try several faculty?); warm up research project towards end of year/summer;
* Year 3: (hopefully) start of partial RA support, research kicks into high gear; take general exam
* Year 4: key year for research productivity as applications for postdocs occur in the fall of...
* Year 5: give seminars, get a postdoc offer in January, write thesis in spring, graduate in spring/summer

If you are interested, please note:

* **Faculty & research jobs are scarce in PT**

  Do you like theory so much to put up with job insecurity for the next ~10 years, with possible postdocs in distant places?

  However, PT PhDs who leave the field find interesting gainful employment (finance, bioinformatics, teaching,...)

* **Need to love the field, be inspired by it, and "let the chips fall where they may"**

  Great place to dip your toe into the field is to attend the (student run) PT Journal Club next quarter or in the spring. Can sit and listen. Once in the PT group, you'll typically give one self-taught talk each quarter.

* **Expect a mix of pen-paper and numerical calculations in most projects**

Openings? Who is graduating?

* 2016: Fuini (Yaffe), Ghalsasi (Nelson) & Horkel (Sharpe)
* 2017: Robinson (Karch), Barton-Rowledge (Nelson)?

I am looking for a new student now!

Where do students go?

* 2015: Seyda Ipek (Nelson) → postdoc at Fermliab
* 2015: Bridget Bertoni (Nelson/Reddy) → postdoc at Stanford
* 2014: Han-Chih Chang (Karch) → postdoc at U. Virginia
* 2014: Max Hansen (Sharpe) → postdoc at U. Mainz
* 2014: Stefan Janiszewski (Karch) → postdoc at U. Victoria
* 2013: Jakub Scholtz (Ellis/Nelson) → postdoc at Harvard
* 2010: Kristen Jensen (Karch) → U. Victoria → Stony Brook → SFSU (faculty)
* 2010: Andrew Lytle (Sharpe)→ Southampton (UK)→Tata Inst. (Mumbai)→Glasgow
* 2010: Steve Paik (Strassler/Karch) → faculty, Santa Monica College
* 2010: Ethan Thompson (Strassler/Karch/Yaffe) → Inst. of Systems Biology
* 2010: Chris Vermillion (Ellis) → U. Louisville → tech. start-up company
* 2010: Jon Walsh (Ellis/Nelson) → LHC postdoc at Berkeley