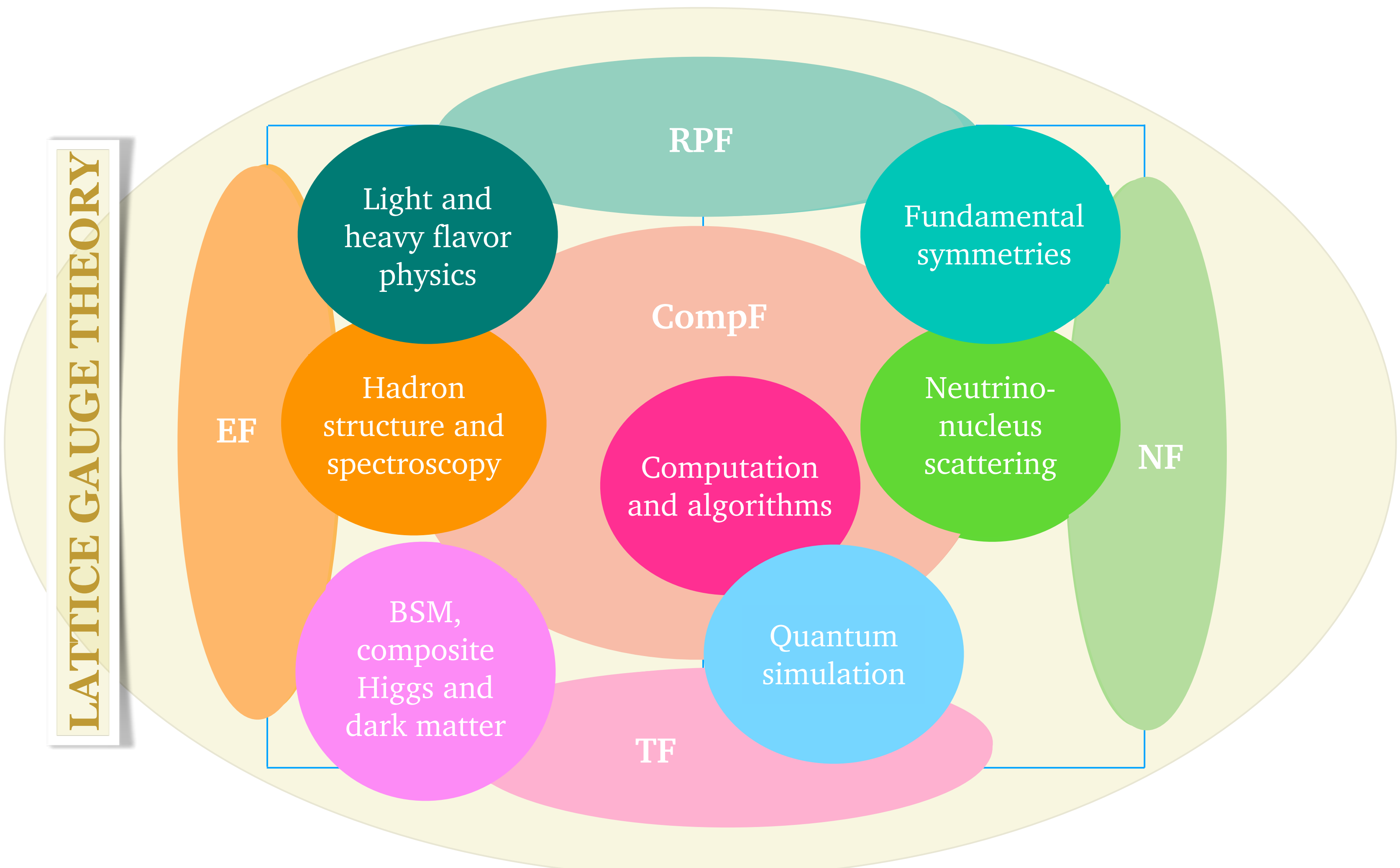
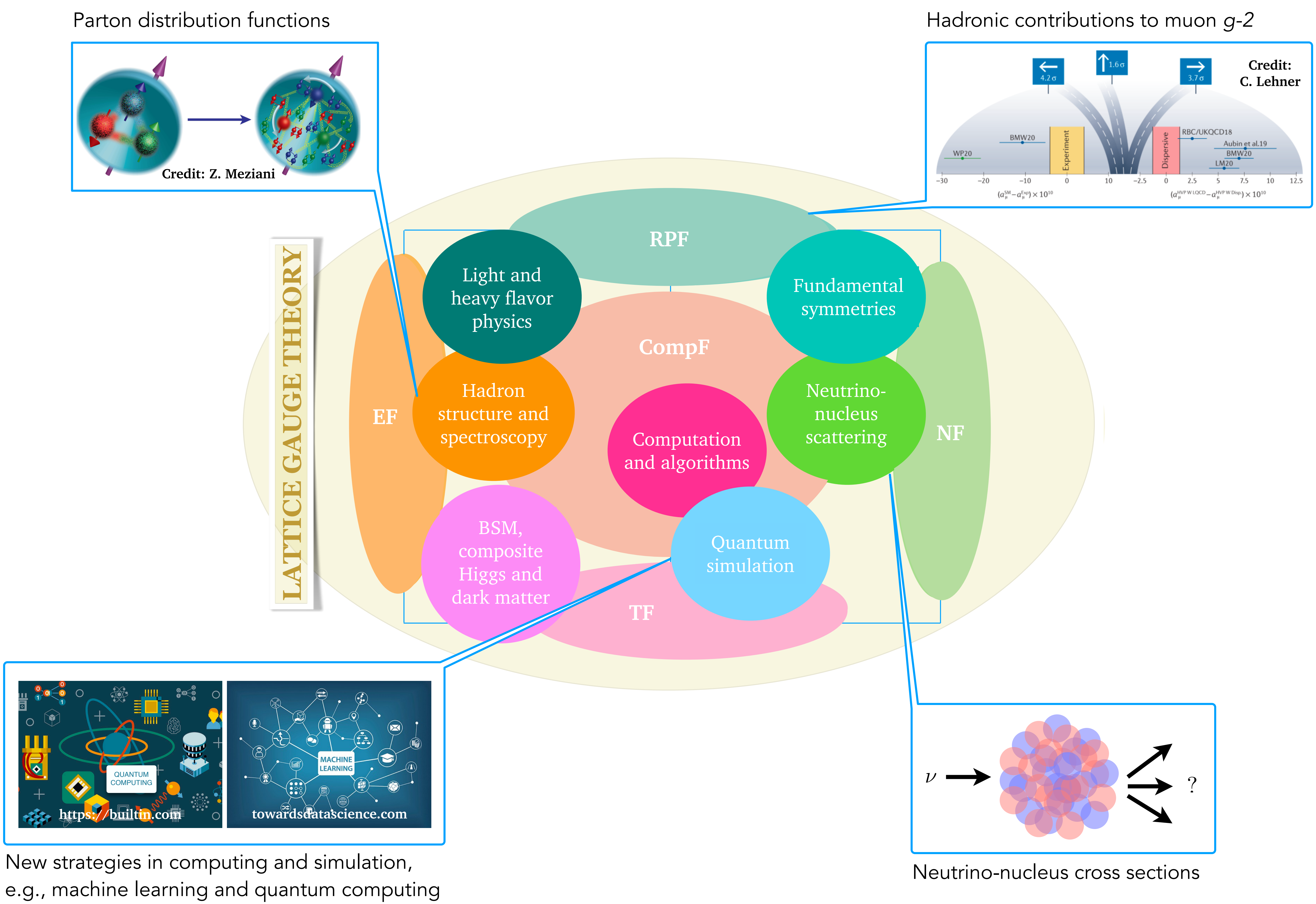
Snowmass Community Summer Study Workshop
July 17-26, 2022, University of Washington, Seattle



LATTICE GAUGE THEORY FOR HEP: OVERVIEW

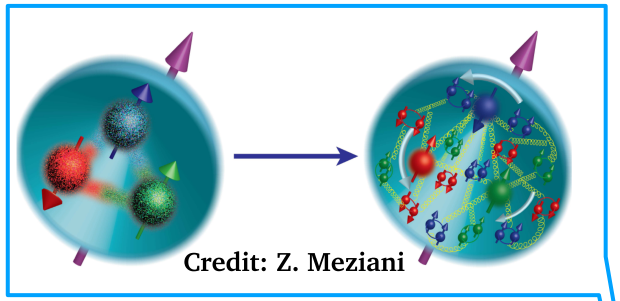
Zohreh Davoudi
University of Maryland, College Park

LATTICE GAUGE THEORY TOUCHES ON ALMOST ALL AREAS OF HEP



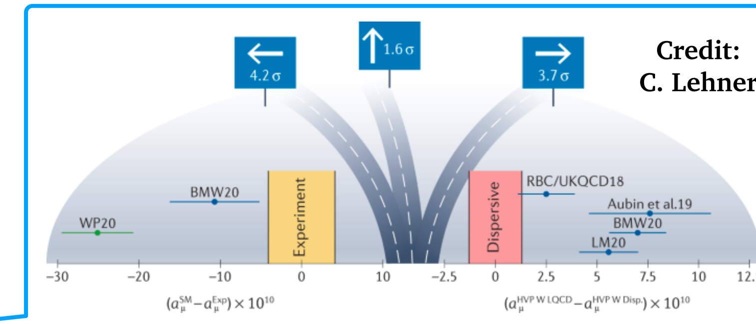
LATTICE GAUGE THEORY TOUCHES ON ALMOST ALL AREAS OF HEP

Parton distribution functions

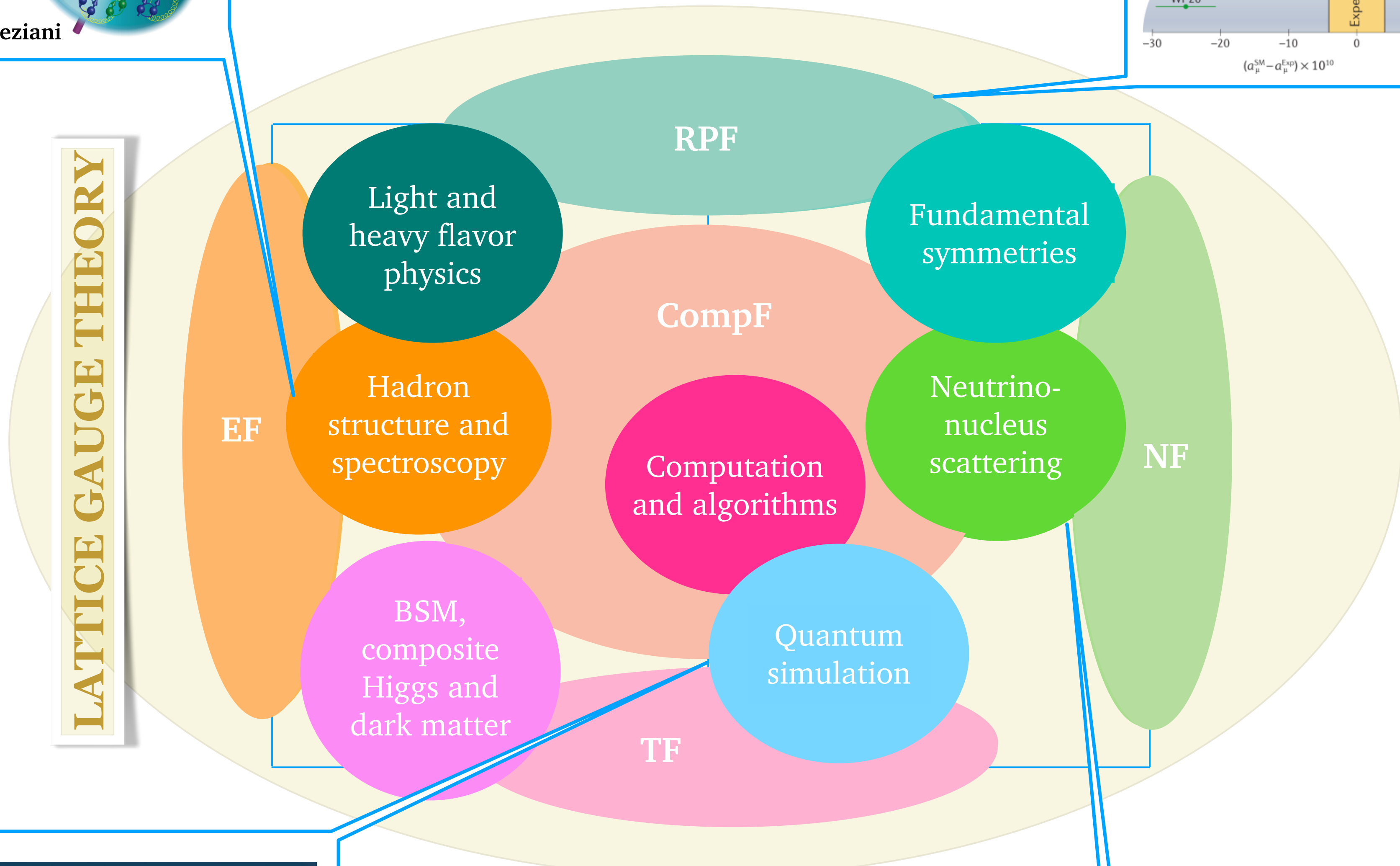


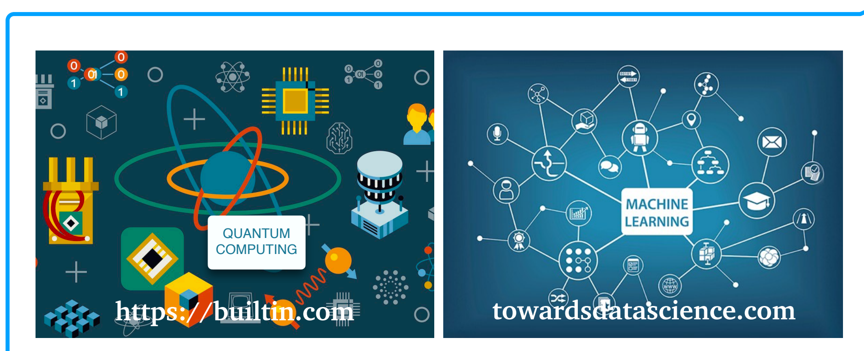
See A. Kronfeld's talk on lattice QCD for precision flavor physics.

Hadronic contributions to muon *g-2*



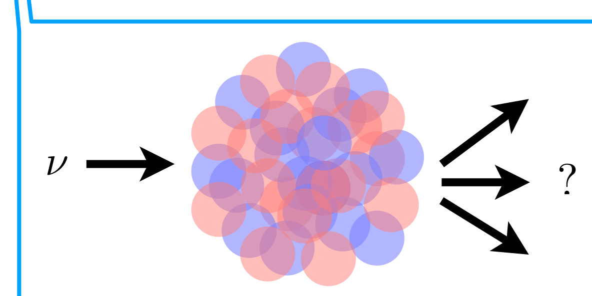
More topics covered in this session.





New strategies in computing and simulation, e.g., machine learning and quantum computing

See ZD's concerning lattice QCD at the nucleon and nuclear frontiers and more exploratory directions.



Neutrino-nucleus cross sections

LATTICE-QCD TALKS AT THE SEATTLE SNOWMASS SUMMER MEETING 2022

3:35 PM **Enabling precision quark- and lepton-flavor physics with lattice QCD**
Speaker: Andreas Kronfeld (Fermilab)
snowmass.pdf

4:05 PM **Uncovering new-physics signals in nucleons and nuclei with lattice QCD,**
Speaker: Zohreh Davoudi (University of Maryland)
LQCD-and-FS-with-n...

4:35 PM **Questions and discussion**

10:15 AM **Lattice Gauge Theory for HEP: Overview**
Speaker: Zohreh Davoudi (University of Maryland)

10:25 AM **Quark and Lepton Flavor Physics**
Speaker: Oliver Witzel (Universität Siegen)

10:44 AM **Nucleons and nuclei for BSM searches and neutrino physics**
Speaker: Michael Wagman (Fermilab)

11:03 AM **Hadron structure for HEP**
Speaker: Huey-Wen Lin (MSU)

11:22 AM **Lattice for BSM exploration**
Speaker: Ethan Neil (University of Colorado, Boulder)

11:41 AM **Computational Trends in LGT**
Speaker: Peter Boyle (Brookhaven National Laboratory)

10:50 AM **Lattice QCD** ¶
Speaker: Christopher Kelly (Brookhaven National Laboratory)
talk_v3.pdf

11:07 AM **Lattice QCD input for the first-row CKM unitarity tests**
(in person)
Speaker: Luchang Jin (BNL)
snowmass2022-latt...

11:06 AM **Hadron Spectroscopy with Lattice QCD**
(remote)
Speaker: M Padmanath (Graz U.)
Padmanath_Lattice...

Lattice for precision studies at the energy frontier
(alphas, mb, ...)
Speaker: Andreas Kronfeld (Fermilab)
EF-TF-alphas-LGT.pdf

SNOWMASS AND LATTICE GAUGE THEORY

- LGT is a numerical non-perturbative methods for r**eliable calculations in strongly-coupled quantum field theories**. It provides ***ab initio*** **predictions for processes involving QCD**.

- Strong overlap with a number of topics in various frontiers, primarily in **EF, RF, NF, and CompF**, as well as other topical areas in the **TF**.

- Received **~60 LOI** as primary or secondary listing and **15+ whitepapers** exclusively on the lattice QCD topic or with a large lattice-QCD component.

- A number of workshops and conferences were co-organized by the lattice gauge theorists within the Snowmass process on topics such as **rare processes and precision measurements, heavy-flavor physics and CKM matrix elements, and neutrino-nucleus scattering**.

- TF05 also organized dedicated sessions and talks at the **(virtual) Snowmass Community Planning Meeting** in October 2020, at the **Theory Frontier Conference** at the Kavli Institute for Theoretical Physics in Santa Barbara, CA in February 2022, and at the **Snowmass Community Summer Study Workshop** at the University of Washington, Seattle, WA in July 2022.

Submitted to the Proceedings of the US Community Study
on the Future of Particle Physics (Snowmass 2021)

Report of the Snowmass 2021 Topical Group on

Lattice Gauge Theory

Zohreh Davoudi[1], Taku Izubuchi[2], and Ethan T. Neil[3]

[1]Maryland Center for Fundamental Physics and Department of Physics, University of Maryland, College Park, MD 20742, USA
[2]Physics Department and RIKEN-BNL Research Center, Brookhaven National Laboratory, Upton, NY 11973, USA
[3]Department of Physics, University of Colorado, Boulder, CO 80309, USA

THE REPORT DRAWS ON A NUMBER OF SNOWMASS WHITEPAPERS…

G. Colangelo et al. Prospects for precise predictions of a_μ in the Standard Model. In *2022 Snowmass Summer Study*, 3 2022.

D. d'Enterria et al. The strong coupling constant: State of the art and the decade ahead. 3 2022.

Thomas Blum et al. Discovering new physics in rare kaon decays. In *2022 Snowmass Summer Study*, 3 2022.

L. Alvarez Ruso et al. Theoretical tools for neutrino scattering: interplay between lattice QCD, EFTs, nuclear physics, phenomenology, and neutrino event generators. 3 2022.

Ricardo Alarcon et al. Electric dipole moments and the search for new physics. In *2022 Snowmass Summer Study*, 3 2022.

Vincenzo Cirigliano et al. Neutrinoless Double-Beta Decay: A Roadmap for Matching Theory to Experiment. 3 2022.

Martha Constantinou et al. Lattice QCD Calculations of Parton Physics. 2 2022.

John Bulava et al. Hadron Spectroscopy with Lattice QCD. In *2022 Snowmass Summer Study*, 3 2022.

Brian Batell, Matthew Low, Ethan T. Neil, and Christopher B. Verhaaren. Review of Neutral Naturalness. In *2022 Snowmass Summer Study*, 3 2022.

Simon Catterall and Joel Giedt. Supersymmetric Lattice Theories: Contribution to Snowmass 2022. 2 2022.

Peter Boyle et al. Lattice QCD and the Computational Frontier. In *2022 Snowmass Summer Study*, 3 2022.

Denis Boyda et al. Applications of Machine Learning to Lattice Quantum Field Theory. In *2022 Snowmass Summer Study*, 2 2022.

Yannick Meurice, James C. Osborn, Ryo Sakai, Judah Unmuth-Yockey, Simon Catterall, and Rolando D. Somma. Tensor networks for High Energy Physics: contribution to Snowmass 2021. In *2022 Snowmass Summer Study*, 3 2022.

Christian W. Bauer, Zohreh Davoudi, et al. Quantum Simulation for High Energy Physics. 4 2022.

Andreas S. Kronfeld et al. Lattice QCD and Particle Physics. 7 2022.

AS WELL AS USQCD'S 2019 WHITEPAPERS…

1) W. Detmold, R. G. Edwards, J. J. Dudek, M. Engelhardt, H.-W. Lin, S. Meinel, K. Orginos, and P. Shanahan (USQCD), Hadrons and nuclei, Eur. Phys. J. **A55**, 193 (2019), arXiv:1904.09512 [hep-lat].
2) A. Bazavov, F. Karsch, S. Mukherjee, and P. Petreczky (USQCD), Hot-dense lattice QCD, Eur. Phys. J. **A55**, 194 (2019), arXiv:1904.09951 [hep-lat].
3) C. Lehner, S. Meinel, T. Blum, N. H. Christ, A. X. El-Khadra, M. T. Hansen, A. S. Kronfeld, J. Laiho, E. T. Neil, S. R. Sharpe, and R. S. Van de Water (USQCD), Opportunities for lattice QCD in quark and lepton flavor physics, Eur. Phys. J. **A55**, 195 (2019), arXiv:1904.09479 [hep-lat].
4) A. S. Kronfeld, D. G. Richards, W. Detmold, R. Gupta, H.-W. Lin, K.-F. Liu, A. S. Meyer, R. Sufian, and S. Syritsin (USQCD), Lattice QCD and neutrino-nucleus scattering, Eur. Phys. J. **A55**, 196 (2019), arXiv:1904.09931 [hep-lat].
5) V. Cirigliano, Z. Davoudi, T. Bhattacharya, T. Izubuchi, P. E. Shanahan, S. Syritsyn, and M. L. Wagman (USQCD), The role of lattice QCD in searches for violations of fundamental symmetries and signals for new physics, Eur. Phys. J. **A55**, 197 (2019), arXiv:1904.09704 [hep-lat].
6) R. Brower, A. Hasenfratz, E. T. Neil, S. Catterall, G. Fleming, J. Giedt, E. Rinaldi, D. Schaich, E. Weinberg, and O. Witzel (USQCD), Lattice gauge theory for physics beyond the Standard Model, Eur. Phys. J. **A55**, 198 (2019), arXiv:1904.09964 [hep-lat].
7) B. Joó, C. Jung, N. H. Christ, W. Detmold, R. Edwards, M. Savage, and P. Shanahan (USQCD), Status and future perspectives for lattice gauge theory calculations to the exascale and beyond, Eur. Phys. J. **A55**, 199 (2019), arXiv:1904.09725 [hep-lat].

PHYSICS REACH

Enabling precision quark- and lepton-flavor physics with lattice QCD

- Muon anomalous magnetic moment and tau decay
- Quark masses and strong coupling constant
- Light quark flavor physics
- Heavy quark flavor physics

Uncovering new-physics signals in nucleons and nuclei with lattice

- Neutrino-nucleus scattering for neutrino phenomenology
- Electric dipole moments for CP violation
- Baryon and lepton number/flavor non-conservation
- Precision β decay for searches of new physics
- QCD calculations for dark matter

Elucidating hadron structure and spectrum for high-energy physics

- Parton distribution functions
- QCD exotica and resonance physics
- Multi-hadron scattering and interactions

Reaching beyond QCD with lattice field theory

- Strongly-coupled extensions of the Standard Model
- Understanding the theory space of strong dynamics
- Pushing the boundaries of particle theory

COMPUTING AND ECOSYSTEM

Advancing theory and computation

- Advancing standard computational algorithms
- Machine-learning applications in lattice field theory
- Hamiltonian-simulation methods and quantum computation

Strengthening the lattice field theory ecosystem

- Hardware and software requirements and computational needs
- Community organization and best practices
- Workforce and career development

SOME KEY MESSAGES

- With an order of magnitude increase in overall computing power over the next decade, **commensurate increases in the computing resources devoted to LGT will be necessary** to ensure that the goals of the program can be achieved. Further innovations in computing algorithms and physics methods will also be necessary.

- Investment in **a diverse human resource with various skillsets** in theory, algorithm, high-performance computing, and numerical analysis is key.

- Need to **keep up with ever-changing computing software and hardware architecture** including machine learning and quantum computing.

- Supporting **dedicated programs for software development and hardware integration** will continue to be critical over the next decade.

- Should continue **engaging with the theoretical and experimental communities** to increase impact and relevance of the computation.

- Need to ensure that the **trained workforce will be retained** in the program, e.g., by creating permanent positions, so that the continuity of the long-term projects will not be disrupted.

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Have we missed an important message?

Please share with us your feedback on the report (best if received by late July).

Links: Draft report and GoogleForm for comments