The State of Theory

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U.S. DEPARTMENT OF ENERGY
Office of Science

SLAC NATIONAL ACCELERATOR LABORATORY

Opening Remarks

I give this talk as a member of the U.S. HEP theoretical physics community

Prisca Cushman will serve as HEPAP chair during the presentation

The HEP Theory Community has Contributed to this Talk

I have received material and comments from a broad representative cross section of the theory community:

Mirjam Cvetic (Penn)
Michael Dine (UCSC)
Steve Giddings (UCSB)
Yuval Grossman (Cornell)
JoAnne Hewett (SLAC)
Patrick Huber (Virginia Tech)
Andreas Kronfeld (FNAL)
Zoltan Ligeti (LBNL)
Michael Peskin (SLAC)
Alexey Petrov (Wayne State)
Laura Reina (FSU)
Marc Sher (William & Mary)
Nathan Seiberg (IAS)
Timothy Tait (UCI)
Mark Trodden (Penn)
Kathryn Zurek (Cal Tech)

I thank everyone for their valuable input

In Remembrance

Ann Nelson 1958 - 2019

Steven Gubser 1972 - 2019

P5 Report: Statement on Theory

The U.S. has leadership in diverse areas of theoretical research in particle physics. A thriving theory program is essential for both identifying new directions for the field and supporting the current experimental program. Theoretical physicists are needed for a variety of crucial activities that include taking the lead in the interpretation and synthesis of a broad range of experimental results, progress in quantum field theory and possible new frameworks for a deeper understanding of Nature, and developing new ideas into testable models. Theoretical research both defines the physics drivers of the field and finds the deep connections among them. As experiments have confronted the Standard Model with increasing sophistication, theoretical research has provided extraordinary advances in calculation techniques, pushing the leading edge of both mathematics and high performance computing.

Intellectual Breadth of the Field

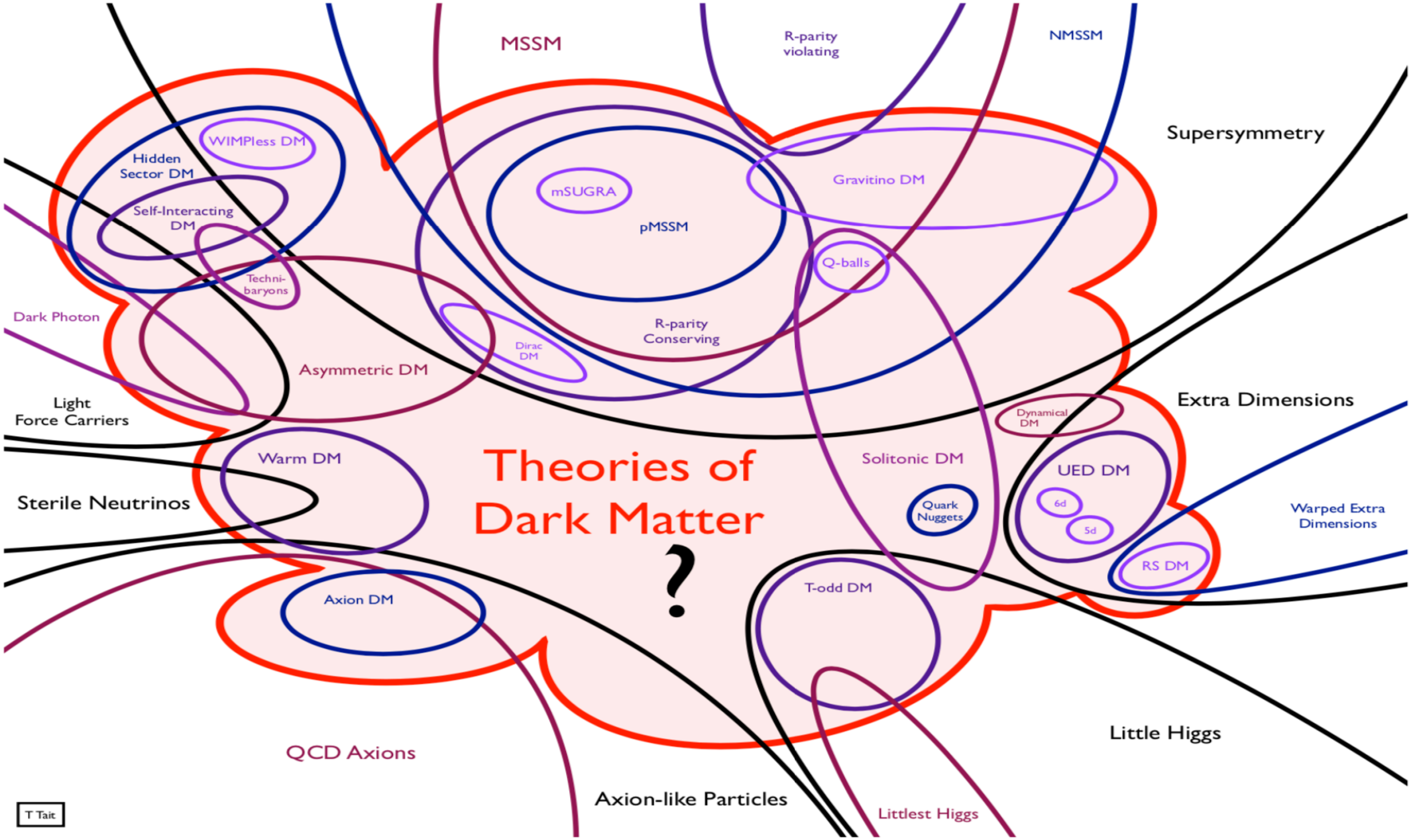
A broad view of theoretical high energy physics is essential

- Example: Higgs discovery
  - Started with abstract field theory work by Higgs and others (with roots in the condensed matter literature)
  - Continued in the work of Weinberg and Salam in model building & construction of the SM
  - Followed by a massive phenomenological effort on possible experimental signatures
  - Followed by a massive effort in precision calculations of SM processes
  - Culminated in the experimental discovery
  - **This achievement could not have taken place if one link in this chain was broken!**

- Example: Connection between perceived distinct fields of study
  - Much interplay and cross fertilization between theoretical high energy physics and condensed matter physics, gravity, pure mathematics, cosmology, and nuclear physics
  - In many cases it is impossible to say whether a given work is in high energy physics or in any of these other fields
  - There are many important discoveries that have influenced more than one field

There are different approaches and styles as well as different topics of research. All of them should be pursued.

Intellectual Health of the Field: BSM & Dark Matter

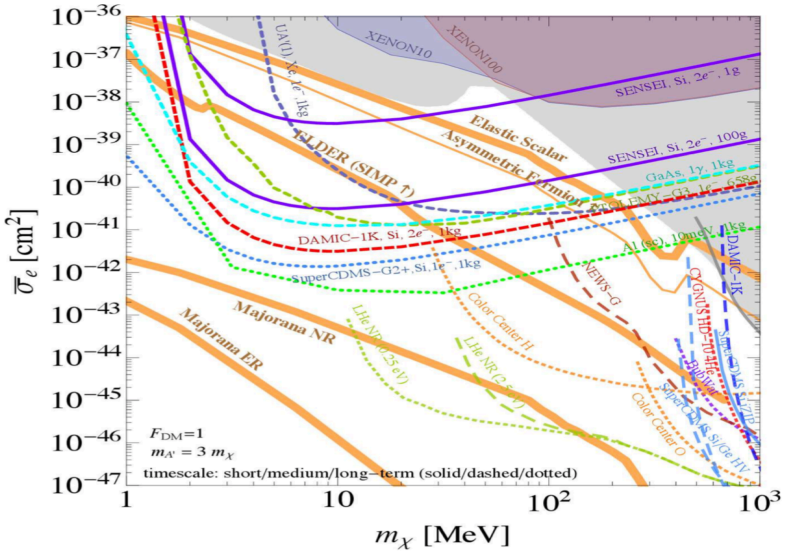


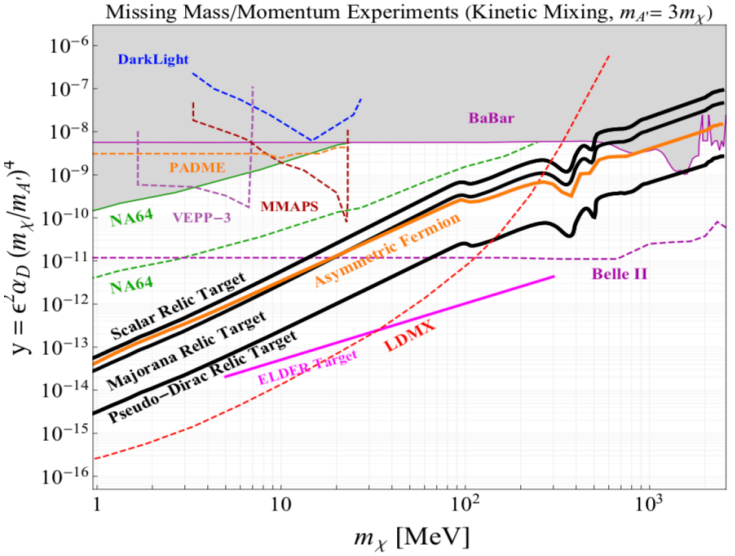
Every single entry in this Venn diagram is a theory generated primarily by US theorists

Intellectual Health of the Field: Dark Matter

At Snowmass 2013:

- Nobody knew the DM electron scattering cross section was an interesting quantity
- Nobody knew there are interesting cosmological targets in this parameter space
- None of these future experiments had been proposed
- All advances due to theorists





Intellectual Health of the Field: Neutrinos

Small size of the neutrino theory community has been recognized

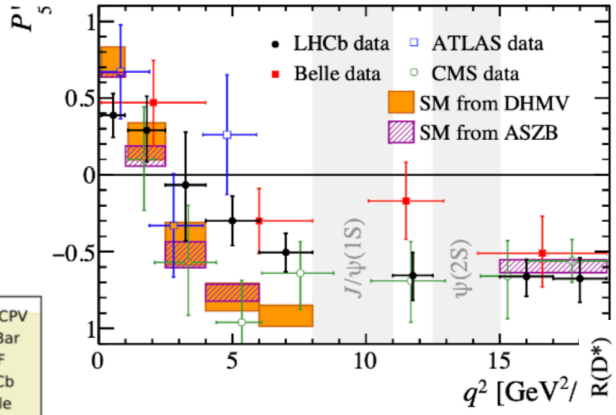
- Small size of community implies few graduate students entering the field
- NSF has funded the N3AS (Network in Neutrinos, Nuclear, Astrophysics and Symmetries) hub with postdoc positions
- DOE has funded the Neutrino Theory Network which is not yet fully defined in scope
- Neutrino theory spans HEP and Nuclear Physics - stove-piping can hinder collaboration

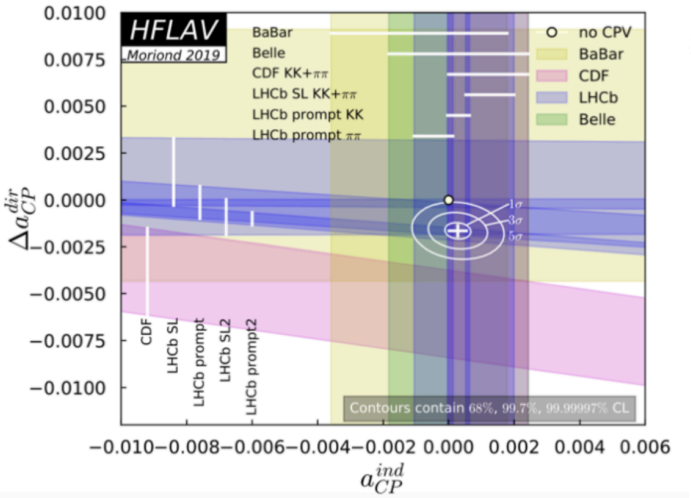
Suggestions to improve the situation

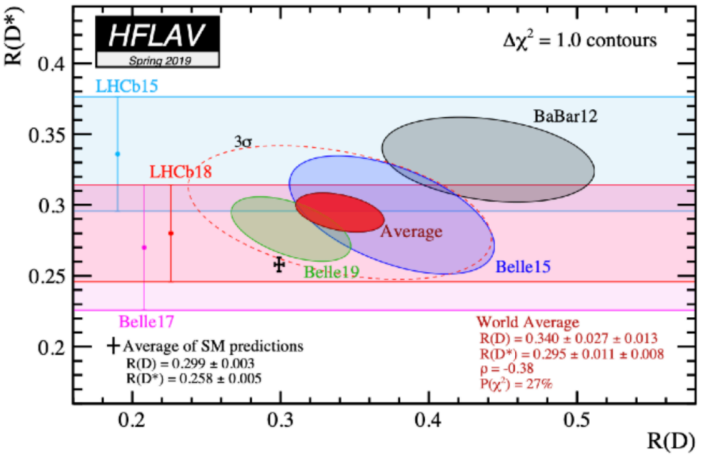
- Targeted faculty bridge program similar to RIKEN
- Neutrino theory initiative should be coordinated across DOE SC and DOE/NSF
- National, named postdoctoral fellowship, modelled after NASA Hubble fellows
- LBNF/DUNE host lab theory group serve as champion for neutrino theory

Intellectual Health of the Field: Flavor Physics

- Most theory activity is outside the U.S., despite the substantial U.S. involvement in Belle II, LHCB, and the lepton flavor program including Mu2e
- Several experimental anomalies to ponder….







Intellectual Health of the Field: Lattice Gauge Theory

DOE Support for cluster computing has been very good

- this funding supports the experimental program and fosters careers of junior researchers
- handful of results with ~1% total uncertainties have been fostered through this effort
- Recognized with early Career Award: 2016
- Improved engagement with community would be beneficial for the future

Intellectual Health of the Field: Formal Theory

Historically the U.S. formal theory community has been the world leader, with forefront contributions to HEP and beyond

- Advances in strongly coupled quantum field theory (gravity/field theory duality, bootstrap program, amplitudes) has implications for particle physics, cosmology and beyond
- Advances in strongly coupled quantum field theory (gravity/field theory duality, bootstrap program, amplitudes) has implications for particle physics, cosmology and beyond
- Geometric advances in particle physics constructions from String/F-theory has implications for the “swampland program”
- Formal theory resides solely in university environment and has undergone significant funding cuts

Intellectual Health of the Field: QCD and Precision Physics - I

Contributors: C. Bauer, R. Boughezal, J. Campbell, S. Dawson, F. Febres Cordero, A. Freitas, S. Hoeche, P. Nadolsky, F. Olness, F. Petriello, L. Reina, M. Schwartz, D. Soper, G. Sterman, J. Thaler, A. von Manteuffel, D. Wackeroth, C. Williams

- The community of theorists working on precision calculations (QCD and Electroweak) in the US is directly addressing some of the major science drivers of the last P5 report, from the exploration of new physics through in-depth studies of the Standard Model (SM) and its quantum-field-theory (QFT) properties, to the development of more and more sophisticated techniques to extract direct and indirect evidence of new physics from existing and future experimental facilities.
- Results from precision calculations to which the US theory community has directly contributed have had a major impact on all LHC searches and measurements so far, notably in pushing the reach of the Higgs-physics program beyond what had been originally envisioned for Run 2, and will become even more crucial in the LHC high-luminosity phase (HL-LHC). At the same time, pushing the precision boundaries of SM calculations has allowed us to get deeper into the general structure of QFT and promises to give access to new groundbreaking intuitions leading to theories beyond the SM.

Intellectual Health of the Field: QCD and Precision Physics - II

- New ideas are emerging to exploit synergies, such as between the HL-LHC and the Electron-Ion-Collider (EIC) physics programs in the next decade. For example, a precision DIS experiment at the EIC will open a unique window to independently constrain the combination of parton distributions relevant for Higgs physics and high-mass resonance searches at the HL-LHC. At the same time, techniques developed to precisely predict hadronic jet properties and find rare events at the HL-LHC will also be of high value for the EIC community.
- Precision calculations are crucial to the interpretation of future data. We have in the US a small but vibrant community, with strong expertise in both foundational and cutting-edge areas of precision physics, but we are lacking the critical mass of people working on it, if we compare with competing programs e.g. in Europe. Precision physics calculation are optimally done with teams, and the US support of such efforts is insufficient and lack the theoretical infrastructure.
- To continue being competitive in precision physics for the next decade of LHC physics, and fully bring to fruition its unique potential, an investment in manpower is needed. One area of weakness is the inadequate funding of postdoc positions in our community, especially when compared to peer groups in Europe.
- Students interest is high, but they are often turned away for lack of support. It is even more worrisome to see that most if not all students in precision physics have to move to Europe for post-graduate research positions. Increased funding for postdocs would help to retain our own talent.

Intellectual Health of the Field: Cosmology

- Cosmology is now firmly established as a high energy physics area and priority, which is a crucial development
- Cosmology is providing many impressive new datasets and posing many big unsolved problems
- This is invigorating theorists

Theory's Future: Post-Docs and Students

Universal comments

- Student interest remains strong – in all areas of theory
- Funding does not match interest
- Students are likely to teach their entire graduate career
  - It is not clear how much longer university departments will support this model
- Difficult university budgets combined with the strong phenomenology program residing at labs causes concern for continued phenomenological student recruitment. This has implications for the future of the field as a whole.

- The number of available post-doctoral positions at U.S. institutions has declined
- Postdoc applications from U.S. educated applicants have decreased in number
- Now normal for U.S. educated students to take postdoc positions abroad
- Common for postdocs at private universities to be funded from non-federal sources
- QIS program has provided some support for formal postdocs and helped to ease the situation

Theory Funding – Universal Comments

- Universal concern on ever decreasing levels of funding for university groups: concern that university programs are dying
  - Private institutions attempt to offset cuts with non-federal funding sources
  - Cuts to program further accumulated in 2019
    - many postdocs learned in May 2019 that their contracts would not be renewed for the fall. It was then too late to apply for new positions.
- Lab theory programs are also losing researchers
- Even distribution of cuts across U.S. theory program has indirect proportional effect to small programs
- Large fluctuations cycle-to-cycle is making groups less cohesive and more inclined to opt for “safer” research projects
- There is the perception that the recent emphasis on QIS comes at a cost to more traditional HEP theory research
- Summer salary has been capped or reduced to 1 month in many cases
  - Removal of summer salary across the board is demoralizing
  - JLH view: People need to be paid for their work

DOE 2016 CoV Statement on Theory

- Work to restore a thriving and intellectually diverse theory program mentioned as essential in the P5 report. Support for theory as a fraction of the research budget should not fall below the current level in order that the scientists ranked in tiers 1, 2, and 3 remain adequately supported.
- Hire an IPA for the Theory program. Such a hire will assist with the heavy peak workload and should help provide a balanced perspective to program.

Summary: U.S. HEP Theory

- Theory is one of the areas of U.S. HEP research that is a traditional strength
- Theory remains an intellectually healthy field
- A vibrant theory program is necessary to keep the engine of successful HEP experimental projects running
- However, there is a feeling in the community that theory is not thriving – for both DOE and NSF
- Reduction in student and postdoc positions is becoming alarming

The situation is becoming increasingly unstable
University-based theory is suffering its most serious crisis in decades
Its future is in jeopardy