3rd Proton Mass Workshop: Origin and Perspective

Welcome

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$$T^{\mu}_{\mu} = \sum_{q=u,d,s} m_q \left(1+\gamma_m\right) \bar{\psi}_q \psi_q + \frac{\tilde{\beta}(g)}{2\,g} G^{\mu\nu}_a G^a_{\mu\nu}$$

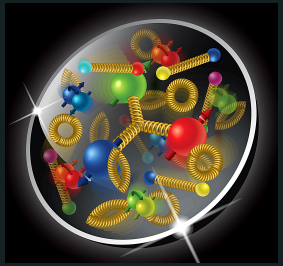
Organizers: Ian Cloët, Xiangdong Ji, Zein-Eddine Meziani, and Jianwei Qiu

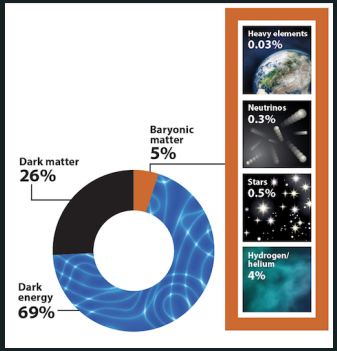
14–16 January 2021

Argonne NATIONAL LABORATORY

Why are we here?

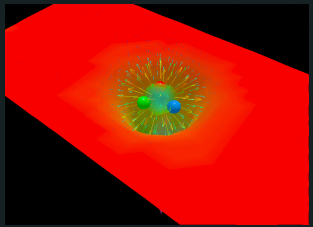
- We are here to discuss one of the most fundamental questions in strong interaction physics: How does the proton get its mass?
  - Intimately connected to the origin of the visible universe
- The proton contains an uncountable number of quarks, anti-quarks, and gluons
  - However, even if the quarks are massless (chiral limit) the proton only gets around 5% lighter (sigma terms)





- The proton gets the vast bulk of its mass from the field energies of the quarks and gluons it contains
  - Deeply connected with emergent phenomena of color confinement and dynamical chiral symmetry breaking – entwined with the trace anomaly

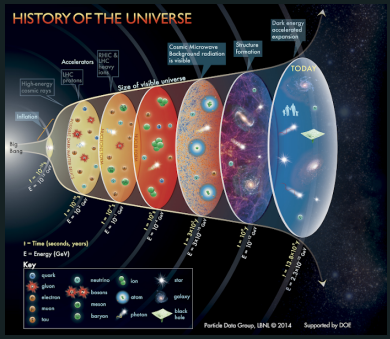
$$\langle N | T^{\mu}_{\mu} | N \rangle = 2\, m_N^2, \qquad \langle \pi | T^{\mu}_{\mu} | \pi \rangle = 2\, m_\pi^2 \xrightarrow{\text{chiral limit}} 0$$

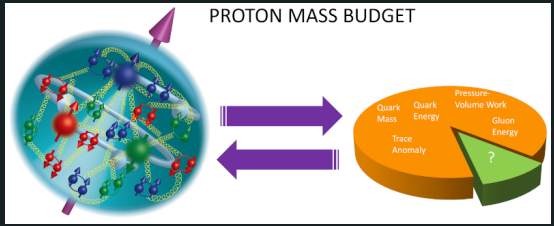


Derek Leinweber (Adelaide)

Finding the Right Questions

- Progress can be accelerated and focused with the right questions. Formulating and refining these questions is a goal for the meeting.
- On the workshop website we have outlined many related questions:
  - What determines the QCD scale and how does it affect the visible universe?
  - What is the role of the trace anomaly in QCD? Does it reflect both color confinement and dimensional transmutation?
  - What is the role and interplay between chiral symmetry breaking and color confinement in determining hadron masses?
  - Can nucleon TMDs reveal the temperature at which the nucleon is formed?
  - What is the interplay between the Higgs and QCD mass generation mechanisms?
  - Can lattice QCD calculate the mass distribution in the nucleon?
- These questions need to be distilled and likely new questions added





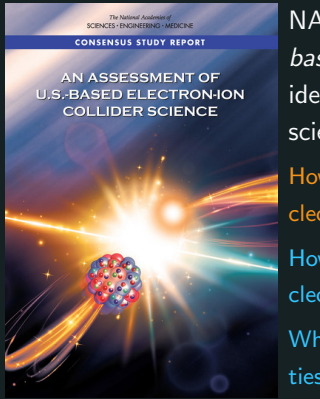
How did we get here?

The 1st proton mass workshop "The Proton Mass: At the heart of most visible matter" was held at Temple University on 28-29 March 2016. Organizers: Zein-Eddine Meziani and Jianwei Qiu

https://phys.cst.temple.edu/~meziani/proton-mass-workshop-2016

The 2nd proton mass workshop was held at the ECT* on 3-7 April 2017. Organizers: Zein-Eddine Meziani, Barbara Pasquini, Jianwei Qiu, and Marc Vanderhaeghen

https://indico.jlab.org/event/194/overview



NAS *Assessment of a U.S. based Electron Ion Collider* identified three high-priority science questions (2018):

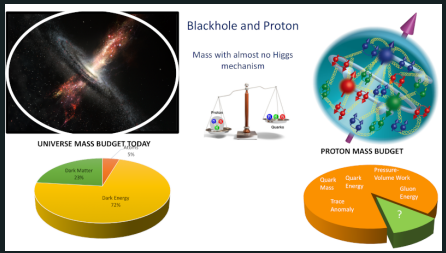
How does the mass of the nucleon arise?

How does the spin of the nucleon arise?

What are the emergent properties of dense systems of gluons?

Where are we going?

- A key goal of this workshop is to produce a White Paper with the working title "Proton Mass: Origin and Perspective"
  - We have a standing invitation to publish in the journal Report on Progress in Physics
  - The following people have agreed to serve as an Editor and contribute to this publication: Constantia Alexandrou, Ian Cloët, Xiangdong Ji, Dima Kharzeev, Zein-Eddine Meziani, Jen-Chieh Peng, Jianwei Qiu, & Marc Vanderhaeghen



- We invite you to contribute a one-page write-up on your research and ideas related to the origin of hadron mass. More on this at the end of the workshop. In the meantime, we invite you to send key question(s) that you think best illuminate the origin of the proton mass (icloet@anl.gov)

INSTITUTE for NUCLEAR THEORY

We will hold the 4th proton mass workshop at the Institute for Nuclear Physics, titled Origin of the Visible Universe: Unraveling the Proton Mass (20-77W), on 6-10 December 2021 [postponed from May 2020]. Organizers: Ian Cloët, Zein-Eddine Meziani, and Barbara Pasquini.

https://www.int.washington.edu/PROGRAMS/20-77W/