FUNDAMENTAL PHYSICS IN SMALL EXPERIMENTS (TOPICAL GROUP 3)

Co-conveners: Tom Blum (UConn) and Peter Winter (ANL)

EDM Sub-conveners: Yannis Semertzidis (IBS-CAPP and KAIST) and
Tanmoy Bhattacharya (LANL)

TOPICAL GROUP MILESTONES

- Topical group represented at several events
  - Workshop on EDMs and MDMs (September 15-17, 2020):
    - Speakers on theory and experimental efforts
  - Received 25 LOIs
  - RPF Town Hall Meeting (October 2, 2020):
    - Short summaries of the received LOIs
  - New Opportunities for Fundamental Physics Research with Radioactive Molecules,Virtual Meeting, June 28 - July 2, 2021 (“AMO meets HEP”)
  - Since Fall 2021:
    Regular meetings with various White Paper groups to coordinate the writing
  - March 2021:
    - Received 13 White Papers to this group

WHITE PAPERS RELEVANT FOR OUR REPORT*

- EDMs:
  - Electric dipole moments and the search for new physics (https://arxiv.org/abs/2203.08103)
  - The storage ring proton EDM experiment (https://arxiv.org/abs/2205.00830)
- MDMs
  - Prospects for precise predictions of a_μ in the Standard Model (https://arxiv.org/pdf/2203.15810.pdf)
  - R measurement and QCD studies at future super τ−charm factory (https://arxiv.org/abs/2203.06961)
  - Belle II physics reach and plans for the next decade and beyond (https://tinyurl.com/ycyaur4y)
  - Upgrading SuperKEKB with a Polarized Electron Beam: Discovery Potential and Proposed Implementation (received but not on arXiv)
- Tests of symmetries and gravity
  - Precision Studies of Spacetime Symmetries and Gravitational Physics (https://arxiv.org/abs/arXiv:2203.09691)
- Sensors
  - Quantum Sensors for HEP Science – Interferometers, Mechanics, Traps, and Clocks (https://arxiv.org/abs/2203.07250)

* Five additional WPs received (PIONEER and on dark matter) will be handled by other topical groups

MAIN TOPICS COVERED IN WHITE PAPERS

- Electric dipole moments (CP violation):
  - General WP covers theory and all major experimental EDMs (neutron, atoms/molecules, storage ring EDMs)
  - Especially relevant for HEP: storage ring EDMs (separate WP)
- Magnetic dipole moments (theory focus):
  - Muon g-2 theory initiative efforts
  - Some related physics (e^+e^-) yielding input to theory
- Precision experiments (HEP and AMO communities):
  - Search for fundamental symmetry violation (C, T, P, Lorentz, CPT)
  - Tests with gravity
- Facilities and techniques:
  - Low-energy muon facility (also relevant to other groups)
  - Quantum sensors for HEP

OVERLAP WITH OTHER COMMUNITIES

- Strong AMO effort (electron, atoms, molecules, ...)
  - Working closely to strengthen ties (Nick Hutzler)
  - Impressive EDM searches already, ambitious goals
- Nuclear Physics: nEDM
- Computational, Theory Frontiers: lattice QCD and p/nEDM, MDM
- Cosmic and neutrino frontier: dark matter / energy
- Theory Frontier: Constraints on BSM
- Other communities with physics overlap:
  - Anti-hydrogen community at CERN
  - Parity violation community at JLab

ELECTRIC DIPOLE MOMENTS

Electric dipole moments and the search for new physics

Ricardo Alarcon,[1] Jim Alexander,[2] Vassilis Anastassopoulos,[3] Takatoshi Aoki,[4] Rick Baartman,[5] Stefan Baeßler,[6,7] Larry Bartoszek,[8] Douglas H. Beck,[9] Franco Bedeschi,[10] Robert Berger,[11] Martin Berz,[12] Hendrick L. Bethlem,[13,14] Tanmoy Bhattacharya,[15,a] Michael Blaskiewicz,[16] Thomas Blum,[17,b] Themis Bowcock,[18] Anastasia Borschevsky,[14] Kevin Brown,[16] Dmitry Budker,[19,20] Sergey Burdin,[18] Brendan C. Casey,[21] Gianluigi Casse,[22] Giovanni Cantatore,[23] Lan Cheng,[24] Timothy Chupp,[22] Vince Cianciolo,[25] Vincenzo Cirigliano,[15,26,c] Steven M. Clayton,[27] Chris Crawford,[28] B. P. Das,[29,30] Hooman Davoudiasl,[16] Jordy de Vries,[31,32,d] David DeMille,[33,34,e] Dmitri Denisov,[16] Milind V. Diwan,[16] John M. Doyle,[35] Jonathan Engel,[36] George Fanourakis,[37] Renee Fatemi,[38] Bradley W. Filippone,[39] Victor V. Flambaum,[40] Timo Fleig,[41,42] Nadia Fomin,[43] Wolfram Fischer,[16] Gerald Gabrielse,[44] R. F. Garcia Ruiz,[45] Antonios Gardikiotis,[46,3] Claudio Gatti,[47] Andrew Geraci,[44] James Gooding,[18] Bob Golub,[48] Peter Graham,[49] Frederick Gray,[50] W. Clark Griffith,[51] Selcuk Haciomeroglu,[52] Gerald Gwinner,[53] Steven Hoekstra,[14,54] Georg H. Hoffstaetter,[2] Haixin Huang,[16] Nicholas R. Hutzler,[55,f] Marco Incagli,[10] Takeyasu M. Ito,[27,g] Taku Izubuchi,[56] Andrew M. Jayich,[57] Hoyong Jeong,[58] David Kaplan,[59] Marin Karuza,[60] David Kawall,[61] On Kim,[52] Ivan Koop,[62] Wolfgang Korsch,[28] Ekaterina Korobkina,[63] Valeri Lebedev,[64,21] Jonathan Lee,[65] Soohyung Lee,[52] Ralf Lehnert,[66] Kent K. H. Leung,[67] Chen-Yu Liu,[66,9,h] Joshua Long,[66,9] Alberto Lusiani,[68,10] William J. Marciano,[16] Marios Maroudas,[3] Andrei Matlashov,[52] Nobuyuki Matsumoto,[69] Richard Mawhorter,[70] Francois Meot,[16] Emanuele Mereghetti,[15] James P. Miller,[71] William M. Morse,[72,i] James Mott,[71,21] Zhanibek Omarov,[52,73] Luis A. Orozco,[74] Christopher M. O'Shaughnessy,[27] Cenap Ozben,[75] SeongTae Park,[52] Robert W. Pattie Jr.,[76] Alexander N. Petrov,[77,78] Giovanni Maria Piacentino,[79] Bradley R. Plaster,[28] Boris Podobedov,[16] Matthew Poelker,[80] Dinko Pocanic,[81] V. S. Prasannaa,[29] Joe Price,[18] Michael J. Ramsey-Musolf,[82,83] Deepak Raparia,[16] Surjeet Rajendran,[59] Matthew Reece,[84,j] Austin Reid,[66] Sergio Rescia,[16] Adam Ritz,[85] B. Lee Roberts,[71] Marianna S. Safronova,[86] Yasuhiro Sakemi,[87] Philipp Schmidt-Wellenburg,[88] Andrea Shindler,[89] Yannis K. Semertzidis,[52,73,k] Alexander Silenko,[64] Jaideep T. Singh,[90] Leonid V. Skripnikov,[77,78] Amarjit Soni,[16] Edward Stephenson,[66] Riad Suleiman,[91] Ayaki Sunaga,[92] Michael Syphers,[93] Sergey Syritsyn,[94] M. R. Tarbutt,[95] Pia Thoerngren,[96] Rob G. E. Timmermans,[97] Volodya Tishchenko,[16] Anatoly V. Titov,[77,78] Nikolaos Tsoupas,[16] Spyros Tzamarias,[98] Alessandro Variola,[47] Graziano Venanzoni,[10] Eva Vilella,[18] Joost Vossebeld,[18] Peter Winter,[99,l] Eunil Won,[58] Anatoli Zelenski,[16] Tanya Zelevinsky,[100,101] Yan Zhou,[102] and Konstantin Zioutas[3]

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[12]*Michigan State University, East Lansing, Michigan, USA*
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- 147+ authors and 12 endorsers
- Encompassing storage rings, ultra-cold neutrons, and atomic and molecular
- Significant theory component
- AMO, HEP, and NP communities
- Talk by Tanmoy Bhattacharya, Wednesday

SCIENCE DRIVERS: EXPLORE UNKNOWN, DARK MATTER/ENERGY

- EDMs (besides QCD theta-term) instant discovery of new physics
- EDM experiments reach energy scales up to 1000's TeV
- Complimentary experiments determine new law(s) of Nature
- Dark matter/dark energy search with srEDM experiment

STORAGE RING EDMS

- Variety of electrically charged particles:

  - Proton:

    proposal by srEDM collaboration to reach 10^{-29} e–cm in 10 years from start of construction, deuteron five years later
  - Muon:

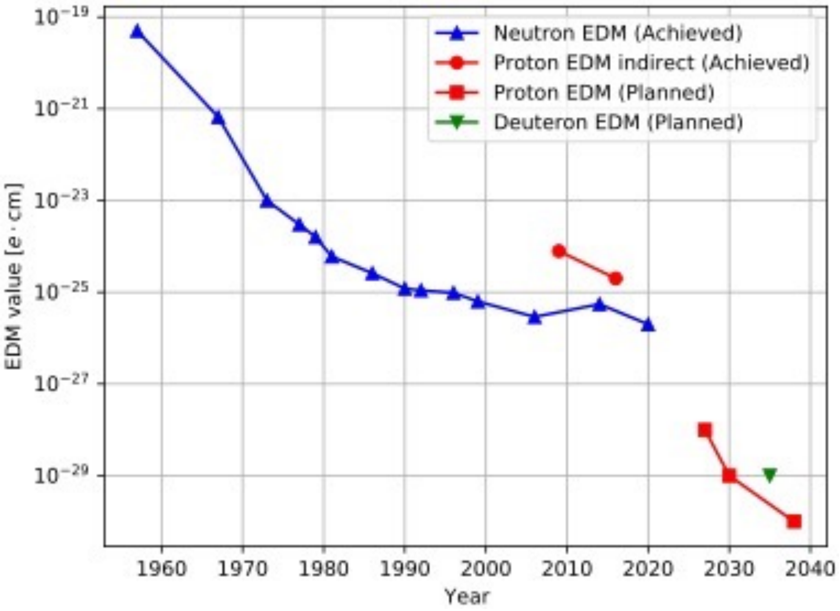
    current limit is 10^{-19} e-cm (BNL E821), 10^{-21} e-cm (FNAL E989, JPARC E34),

    new experiment at PSI, $6x10^{-23}$ after 1 year
  - Electron:

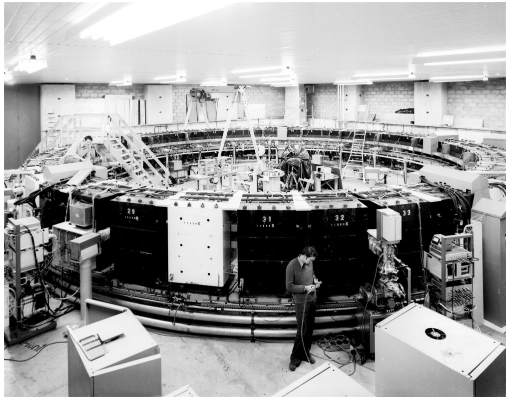
    Proposed small experiment at JLab, beam energy 1 MeV or below

PROTON srEDM EXPERIMENT

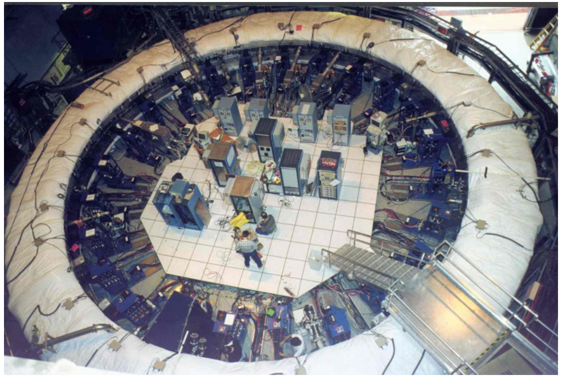
- Based on muon g-2 storage ring experiments (frequency measurement)
- Site at BNL in AGS tunnel to defray cost
- First results in five years after start of construction
- Ultimate sensitivity 10^{-29} e-cm, threes orders below current nEDM
- Robust “hybrid” design, CW and CCW beams cancel largest systematics
- Dark matter/Dark energy search capable
- Path to upgrade to deuteron additional 5 yrs
- srEDM white paper (arXiv:2205.00830)
- Talk by Yannis Semertzidis on Thursday



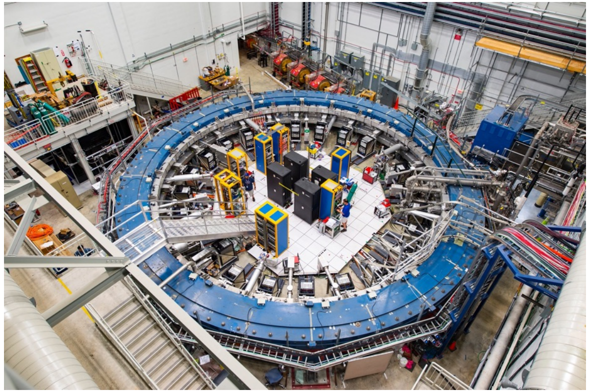
EDM STORAGE RING EXPERIMENTS BASED ON SUCCESSFUL MUON *g*-2 EXPERIMENTS



CERN (1959-1979)



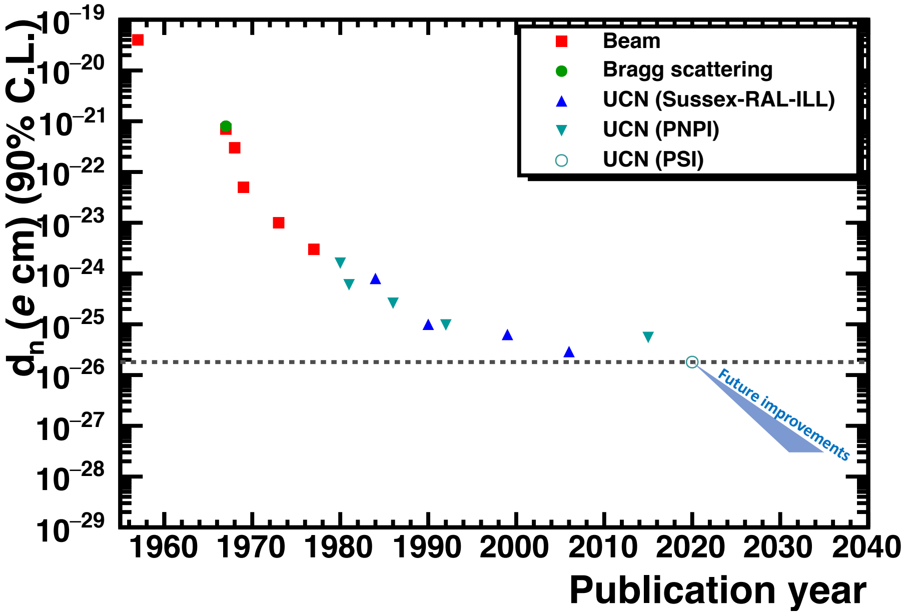
BNL E821(1997-2001)



FNAL E989 (2018-)

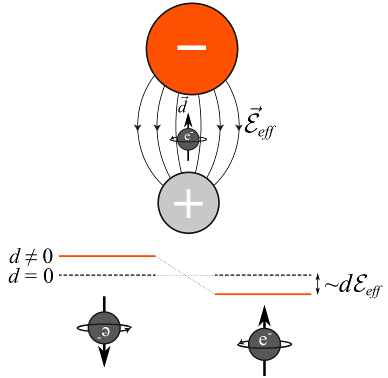
NEUTRON EDM EXPERIMENTS

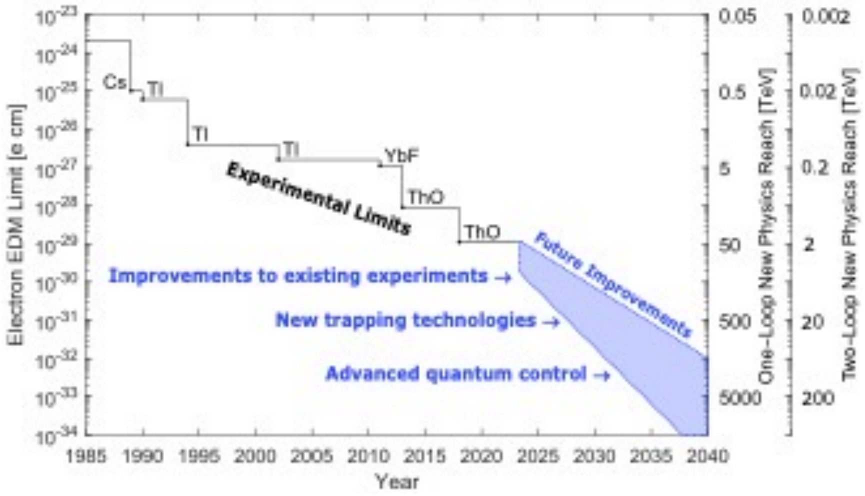
- First EDM measurements
  (Purcell and Ramsey in 1949)
- nEDM sensitive to θ-QCD, quark EDM, quark chromo-EDM, gluon chromo-EDM, CP-violating four-fermi interactions
- Modern experiments use ultracold neutrons (UCN), polarized, stored in rm-temperature bottles for 100's secs
- Techniques developed around the world over decades, best limit of $d_n < 1.8\times10^{-26}$ e·cm (90% C.L.) (PSI, 2020).
- UCN experiments being developed around the world: 10^{-27} within the next 5–10 years and 10^{-28} in 10–15 years.



AMO EDM EXPERIMENTS

- Like neutrons, sensitive probes of EDMs for decades
- Set best limits on the electron EDM, semileptonic CP-violating four-fermi interactions, and quark chromo-EDMs
- Competitive with the nEDM for quark EDMs, θ-QCD; excellent check on both types of experiments.
- Improvements of 1, 2-3, and 4-6 orders of magnitude realistic on few, 5–10, 15–20 year time scales
- Major advancements possibe with quantum science techniques, increasing availability of exotic species with extreme sensitivity.
- Exciting pathway to probe PeV-scale physics using “tabletop” scale experiments
- Talk by Dave DeMille on Thursday





EDM THEORY

- Originate at a high mass scale through new complex CP-violating phases
- Feed to lower energy scales via dimension four and higher operators in a Standard Model effective theory (OPE)
- Elementary particle EDMs manifest in bound states, *e.g.* proton, neutron, atoms and molecules
- At the quark-nucleon level, lattice QCD plays a crucial role
- Lower energies: nucleon chiral perturbation theory, and finally, theories of nuclei, atoms, and molecules
- Reverse holds: measurement of nucleon, atomic, or molecular EDM tests/diagnoses underlying BSM physics
- Effective theory framework encompasses tens-of-orders of magnitude in energy!
- low-energy theory continually improved as new high energy models invented.

MAGNETIC DIPOLE MOMENTS

- Muon g-2 Theory Initiative: Prospects for precise predictions of aμ in the Standard Model

  Ruth Van de Water, Tuesday

- R measurement and QCD studies at future super tau−charm factory Guangshun Huang, Tuesday

- Belle II physics reach and plans for the next decade and beyond Anselm Vossen, Tom Browder, Tuesday

- Upgrading SuperKEKB with a Polarized Electron Beam: Discovery Potential and Proposed Implementation

  Swagato Banerjee, Tuesday

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

FERMILAB-CONF-22-236-T LTH 1303 MITP-22-030

arXiv:2203.15810v1 [hep-ph] 29 Mar 2022

Prospects for precise predictions of a_μ in the Standard Model

for Snowmass RF03

arXiv:2203.06961v1 [hep-ex] 14 Mar 2022

R measurement and QCD studies at future super $\tau - c$ factory

Guangshun Huang*, Wenbiao Yan and Xiaorong Zhou
(On behalf of STCF working group)
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Abstract

We review status of R measurement and QCD studies at low energy range, discuss prospects for a super τ−charm factory in $2-7$ GeV. With a high-luminosity e^+e^- collider, statistics are no longer problem for R measurement and a precision of 2% or even better is foreseen, that will lead to bring down the uncertainty of hadronic contribution to the QED running coupling constant $\Delta\alpha_{had}$ and the anomalous magnetic moment of the muon (a_μ); measure the strong coupling constant α_s and the charm quark mass; improve the measurement of the resonance parameters of heavy charmonia. Huge data samples in $2-3$ GeV will make it possible to study excited states of ρ, ω and ϕ, or exotic $Y(2175)$; measure electromagnetic form factor of mesons and baryons; and measure fragmentation functions of hadrons.

1 Introduction

Super τ−charm factories (STCF) have been proposed in China [1] and Russia [2], presumably to work in $2-7$ GeV, which is a bridge between the perturbative and non perturbative energy region. It is therefore an important area that is of particular interest for testing QCD predictions. The STCF will be one of the crucial precision frontier for exploring the nature of non-perturbative strong interactions. The experimental data will provide essential information to study QCD dynamics of confinement through the study of hadron spectroscopy. Specifically, high-statistics data will significantly improve the following measurements and studies:

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1

arXiv:2204.02280v2 [hep-ex] 13 Apr 2022

Opportunities for precision QCD physics in hadronization at Belle II – a Snowmass whitepaper

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

Snowmass 2021 White Paper
Upgrading SuperKEKB with a Polarized Electron Beam: Discovery Potential and Proposed Implementation

April 13, 2022

US Belle II Group [1]
and
Belle II/SuperKEKB e- Polarization Upgrade Working Group [2]

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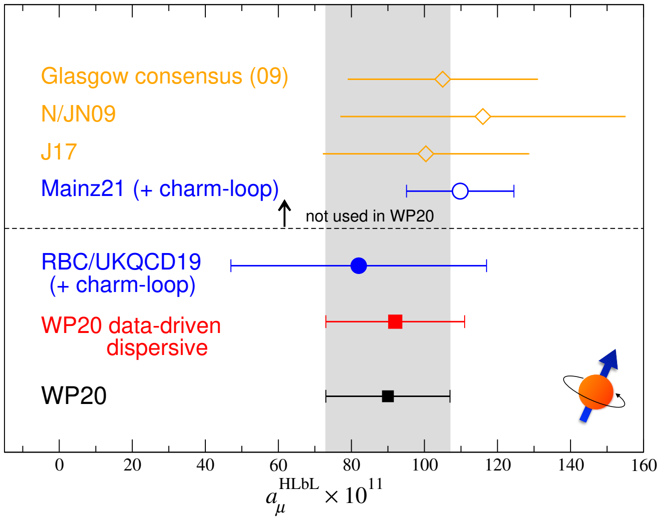
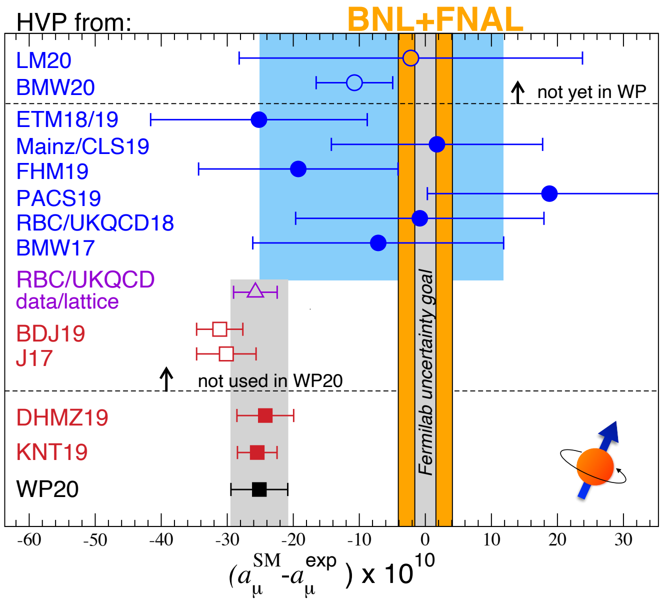
Thematic Area(s):
■ (RF0) Frontier for Rare Processes and Precision Measurements
■ (RF01) Weak Decays of b and c
■ (RF02) Strange & Light Quarks
■ (RF03) Fundamental Physics in Small Experiments
■ (RF05) Charged Lepton Flavor Violation (electrons, muons and taus)
■ (RF06) Dark Sector at Low Energies
■ (AF05) Accelerators for rare processes and precision measurements
■ (EF04) EW Physics: EW Precision Physics and constraining new physics

SCIENCE DRIVER: EXPLORE THE UNKNOWN

- MDMs probe NP scales few TeV, test/diagnose BSM theories
- Complimentary with B-sector anomalies
- Hadronic contributions dominate theory uncertainties
  - Data-driven, dispersive approach key to sub-percent precision
  - Lattice QCD increasingly important
  - Consistency mandatory for NP discovery
- New data from BaBar, Belle-II, CMD-3, BESIII soon and from charm-tau factories later
- New generation of sub-percent lattice calculations in 1-2 years

MUON G-2 THEORY INITIATIVE UPDATE





- HVP by 2025: data driven 0.3% errors, lattice 0.5%
- HLbL by 2025: 10% errors from data driven, lattice

NEW $e^+e^- \rightarrow$ HADRONS MEASUREMENTS
(BELLE II, SUPER TAU-CHARM FACTORY 2203.06961)

- Current data driven uncertainty dominated by systematic difference between BaBar and KLOE data sets for two pion channel
- New data from Belle II, CMD-3, BESIII for two-pion channel crucial
  - If resolved, could cut error roughly in half
- Belle II: goal of 0.4% error on HVP contribution (0.58% currently)
  - Highest luminosity e^+e^- machine
  - Semi-leptonic τ decay measurements
  - Data driven HLbL: axial vector form factors
- Super τ−charm factory in 2−7 GeV [Guangshun Huang, Wenbiao Yan, Xiaorong Zhou]
  - high-luminosity $e+e-$ collider
  - R-ratio precision of 2% or even better in 2-7 GeV range
  - Reduce the uncertainty of hadronic contribution to the QED running coupling constant anomalous magnetic moment of the muon

τ DIPOLE MOMENTS (BELLE II)

- SuperKEKB upgrade: polarized electron beam
- *g*-2: 10^{-5} precision (40 ab^{-1}) and up to 10^{-6}
  - current precision less than Schwinger term
  - probe $e^+e^- \to \tau^+\tau^-$ at 10 GeV^2 for BSM effects
- τ EDM: 10^{-19} e-cm (50 ab^{-1}) probes many interesting new physics models, with pol. upgrade to 10^{-20}

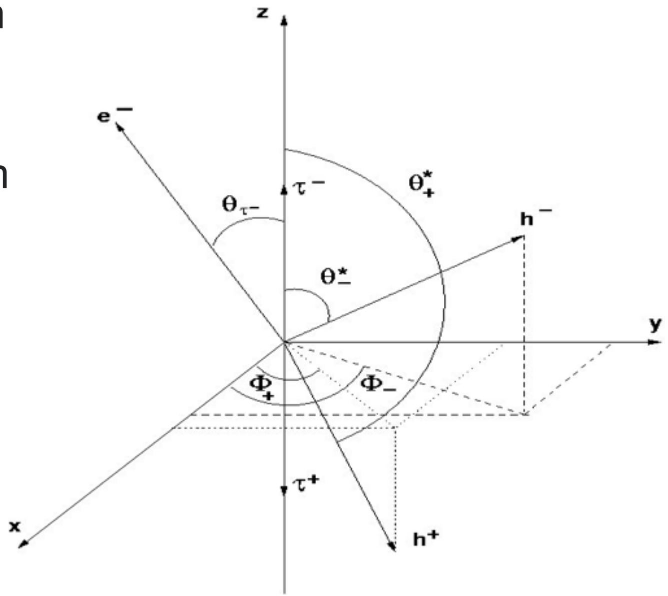


Figure 10: Coordinate system for $e^+e^- \to \tau^+\tau^-$; $\tau^+ \to h^+\bar{\nu}_\tau$ and $\tau^- \to h^-\nu_\tau$ events used in τ $g-2$ and EDM measurements [31]. Here the z-axis is aligned with τ^- momentum, $\theta_{\tau-}$ is the production angle of the τ with respect to the beam electron direction in the center-of-mass, and the azimuthal and polar angles of the produced hadrons, $h^\pm$, in $\tau^\pm$ rest frame, are $\phi_\pm$ and $\theta^*_\pm$, respectively. The tau production plane and direction of flight are fully reconstructed using the technique described in Ref. [27].

PRECISION STUDIES OF SPACETIME SYMMETRIES AND GRAVITATIONAL PHYSICS

Snowmass White Paper: Precision Studies of Spacetime Symmetries and Gravitational Physics

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

Eric Adelberger[1], Dmitry Budker[2], Ron Folman[3], Andrew A. Geraci[a,4], Jason T. Harke[b,5], Daniel M. Kaplan[c,6], Derek F. Jackson Kimball[7], Ralf Lehnert[d,8], David Moore[9], Gavin W. Morley[10], Anthony Palladino[e,11], Thomas J. Phillips[12], Giovanni M. Piacentino[12,13,14], William Michael Snow[f,8,15], and Vivishek Sudhir[g,16]

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- 15 lead authors + endorsers list still being assembled
- Precision tests of symmetries and gravity
- Wide set of low-energy approaches complementary to large-scale facilities
- AMO, HEP, and NP communities
- Talk by Ralf Lehnert on Tuesday

SCIENCE DRIVER: SEARCH FOR THE UNKNOWN

- **Tests of Spacetime Symmetries** with orders of magnitude improvements for various SM extension
  - Search for T-odd/P-odd interactions with NOPTREX
  - Lorentz and CPT tests with various low-energy experiments
- Tests with gravity: fundamental symmetries, GR, quantum nature, short-range corrections
  - Antimatter gravity tests with MAGE
  - Gravitational effects on CP violation
  - Tests of general relativity with a ^{229}Th nuclear clock
  - Mechanical tests of the quantum-gravity
  - Searches for short-range corrections to gravity

NOPTREX: PROPOSAL FOR SEARCH OF TIME REVERSAL WITH NEUTRONS

- Search for **new sources of T-odd/P-odd interactions**
- Based on **neutron interaction in heavy nuclei** providing enhanced sensitivity
- Complementary to EDM searches in ground states
- Method quite insensitive to resonant state properties and final state interaction
- Four months of data taking with MW-class short-pulse neutron source would give order of magnitude improved sensitivity
- NOPTREX could be **converted to spin-spin interferometer** to isolate T-odd/P-odd signal from many backgrounds

LORENTZ AND CPT TESTS WITH VARIOUS APPROACHES (NOT ALL LISTED HERE)

Antiprotons, Penning traps, and atomic clocks

- **Antiprotons** at CERN for Lorentz and CPT tests:
  - ALPHA and ASACUSA:
    - Antihydrogen hyperfine measurements
  - AEgIS, ALHPA-g, GBAR and other experiments:
    - Study antimatter gravity
- **Penning traps**:
  - New bounds for Lorentz and CPT tests with charged particles
  - Sidereal variations of anomaly frequency of trapped (anti)particles
- **Atomic clocks**:
  - Provide some of the sharpest Lorentz-violation bounds for p, n, e, and γ
  - Steady improvements in clock precision will continue

LORENTZ AND CPT TESTS WITH VARIOUS APPROACHES (NOT ALL LISTED HERE)

Cold neutrons, interferometers, and muons

- **Cold neutrons**:
  - Future results from nEDM experiments worldwide will provide ~2 orders of magnitude better sensitivities
  - Planned NNbar experiment probes neutron-antineutron oscillations
- **Matter-wave interferometers**:
  - Lorentz violation can modify the interaction of gravity and matter
  - Matter-wave interferometers or gravimeters are sensitive to such effects
  - Progress with multispecies operation or large wave-packet separation
- **Muons**:
  - Muon g-2 (μ^+ and μ^-) provides access to both Lorentz and direct CPT tests
  - Muonic systems like muonium offer another path for such tests

TESTS OF FUNDAMENTAL SYMMETRIES WITH GRAVITY

Antimatter gravity with MAGE and studies of CPV effects

- **MAGE**
  - Muonium provides **theoretically clean** access to antimatter gravity
  - High-quality muon beam + interferometer to measure small phase shift
  - **Possible 5σ determination of $\bar{g}$ at PSI** with one month data taking
  - Alternative approach **at Fermilab could give 10%** (1% with future Fermilab facility) measurement of $\bar{g}$
- **CPV effects**:
  - Indirect measurement of antimatter gravity with kaons by measuring the **dependence of CP-violation on the gravitational field intensity**
  - Many SME imply large CP violation and antigravity
  - Measure the ratio of 2π and 3π decays of K_L in low-Earth orbit or on the moon
  - Use incident cosmic rays to produce K_L in absence of particle accelerator

TESTS OF GR, QUANTUM EFFECTS AND SHORT-RANGE MODIFICATIONS TO GRAVITY

- ^{229}Th clock:
  - Nuclear transition low enough for laser excitation promises novel clock with 2-3 orders better precision enabling new tests of GR
  - Ongoing R&D needed to better understand energy and half-life of ^{229m}Th
- **Mechanical tests of quantum-gravity interface**:
  - Low energy tests with entangled masses as alternative to tests at Planck scale
  - Two classes of experiments:
    - Interferometric tests with nanoparticles are planned on Earth and in space
    - Non-interferometric tests measure subtle effects of gravitat. entanglement
- **Short-range modifications to gravity:**
  - Study behavior of gravity at sub-millimeter distances to fill gap between quantum gravity and EW scale of SM
  - Prominent techniques include torsion pendulums, slow neutrons, and optically levitated dielectric objects

QUANTUM SENSORS

arXiv:2203.07250v1 [quant-ph] 14 Mar 2022

Snowmass 2021: Quantum Sensors for HEP Science - Interferometers, Mechanics, Traps, and Clocks

Daniel Carney,[1] Thomas Cecil,[2] John Ellis,[3] R.F. Garcia Ruiz,[4] Andrew A. Geraci,[5] David Hanneke,[6] Jason Hogan,[7] Nicholas R. Hutzler,[8] Andrew Jayich,[9] Shimon Kolkowitz,[10] Gavin W. Morley,[11] Holger Müller,[12] Zachary Pagel,[12] Cristian Panda,[12] and Marianna S. Safronova[13]

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- 15 lead authors
- Overview of quantum sensors, future opportunities and their application
- Techniques used for gravitational waves, dark matter / energy, fifth force or fundamental constants
- AMO, HEP, and NP communities
- Talk by Andrew Gerarci on Wednesday

ENABLING FUTURE SCIENCE THROUGH TECHNOLOGY

- Many detectors **reach limits in sensitivity, where quantum laws matter**
- Quantum sensors are **employed in many areas** of physics, e.g.
  - Precise measurement of fundamental constants
  - Searches for dark matter, dynamic sources of dark energy, gravitational waves, fifth forces etc.
- An incomplete list of techniques in this WP:
  - Atom interferometers
  - Optomechanical sensors
  - Clocks
  - Trapped atoms / molecules

QUANTUM SENSOR TECHNIQUES

Atom interferometers and optomechanical sensors

- **Atom interferometers**
  - Applications: GW detection, dark matter/energy to fundamental constants, …
  - **Several configurations** of interferometers like long-baseline with freely falling atoms for GW detection or short-baseline for measurement of α
  - **Differential readout** of two interferometers to **cancel common noise**
  - Future improvements are on the horizon to further increase sensitivity
- **Optomechanical sensors**
  - Applications: GW, precision metrology, dark matter, neutrinos, fifth-force
  - Mechanical sensors readout by light-wave detection have seen tremendous progress and are now often operated in quantum regime
  - Very good for **detecting signals acting coherently** over the size of sensor

QUANTUM SENSOR TECHNIQUES

Clocks and trapped atoms / molecules

- **Clocks**
  - Precision **steadily improving** with applications in many areas
  - Comparison of two clocks **sensitive to α and dark matter**
  - Enhanced sensitivity for heavier atoms
  - Ongoing progress to reach / surpass quantum limits and novel clocks (e.g., nuclear, molecular)
- **Trapped atoms / molecules**
  - Radioactive atoms/molecules offer **extreme charge and deformations**
  - Sensitivity to symmetry violation scales Z^2 – Z^5
  - Difficult to produce so **efficient traps are critical** to use them
  - Ongoing R&D for ion and neutral traps

TOPICAL GROUP ACTIVITIES THIS WEEK

Please join us to discuss the WPs and help writing the report

- White Paper summary presentations:
  - Tuesday, 11:00am-12:30pm: MDMs and Precision Studies
  - Wednesday, 11:00am-11:30am: EDMs and Quantum Sensors

- Topical Report working sessions:
  - Tuesday, 2:00-3:30pm:
    - MDMs section led by Tom
    - Precision Studies section led by Peter
  - Wednesday, 2:00-3:30pm:
    - EDM section led by Tom
    - Facilities, techniques, sensors section led by Peter

TOPICAL REPORT

- Topical report draft based on the WP detailed above
- Tuesday and Wednesday afternoon sessions offer a first opportunity for input
- Will further distribute the report later for wider feedback by WP authors

CONTENTS

PLANS FOR SNOWMASS SUMMER STUDY

- Schedule not yet finalized
- We anticipate:
  - Parallel sessions to discuss the white papers, status of the topical report, feedback
  - Colloquium on EDMs with focus on storage ring EDM opportunity
  - Panel discussion for AMO meets HEP
- Your feedback / input is welcome

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SUMMARY

- Tests of fundamental symmetries (P, CP, CPT,...) offer a compelling program for the next decade:
  - **EDMs strong part of the next decade's research program**, especially with prospects for storage ring EDMs, ongoing nEDM experiments, and complimentary AMO experiments
  - **Magnetic dipole moments** (electron, muon, tau) also have timelines that **span the next decade**; the Fermilab Muon g-2 result may clarify the path forward
  - **A large active community for precision tests** of T, P, CPT, Lorentz and gravity in AMO, NP, and HEP
  - A lot of experimental / sensor techniques are **applicable across multiple communities**, need to share knowledge and opportunities for collaboration