Rare processes and Precision Measurements @ Snowmass

Frontier for Rare Processes and Precision Measurements

Alexey A. Petrov
Wayne State University

Frontier for Rare Processes and Precision Measurements

SnowMass2021

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RARE PROCESSES AND PRECISION MEASUREMENTS

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Frontier Conveners

Name	Institution	email
Marina Artuso	Syracuse University	martuso[at]syr.edu
Bob Bernstein	Fermi National Accelerator Lab	rhbob[at]fnal.gov
Alexey A Petrov	Wayne State University	apetrov[at]wayne.edu

Description

The Frontier for Rare Processes and Precision Measurements explores fundamental physics with intense sources and ultra-sensitive detectors. It encompasses seeking tiny deviations from Standard Model expectations in properties and transitions of elementary particle and searches for extremely rare processes. The Frontier for Rare Processes and Precision Measurements experiments use precision measurements to probe quantum effects and employ sophisticated theoretical techniques for their interpretations. These experiments typically investigate new laws of physics that manifest themselves at higher energies or weaker interactions than those directly accessible at high-energy particle accelerators. These experiments require the greatest possible beam intensities of electrons, muons, photons or hadrons, as well as large detectors, which provide an opportunity for substantial new discoveries complementary to other Frontier experiments.

https://snowmass21.org/rare/start

Frontier for Rare Processes and Precision Measurements

Topical groups

Conveners: theorist/exprimentalist

- RF1: Weak decays of b and c quarks (Angelo Di Canto/Stefan Meinel)
- RF2: Weak decays of strange and light quarks (Evgueni Goudzovski/Emilie Passemar)
- RF3: Fundamental Physics in Small Experiments (Tom Blum/Peter Winter)
- RF4: Baryon and Lepton Number Violating Processes (Pavel Fileviez Perez/Andrea Pocar)
- RF5: Charged Lepton Flavor Violation (electrons, muons and taus) (Bertrand Echenard/Sacha Davidson)
- RF6: Dark Sector Studies at High Intensities (Mike Williams/Stefania Gori)
- RF7: Hadron Spectroscopy (Tomasz Skwarnicki/Richard Lebed)

Liaisons with other frontiers:

- Energy Frontier: Angelo Di Canto
- Neutrino Frontier: Bob Bernstein
- Cosmic Frontier: Susan Gardner
- Theory Frontier: Alexey Petrov
- Accelerator Frontier: Bob Bernstein
- Instrumentation Frontier: Marina Artuso
- Computational Frontier: Stefan Meinel
- Community Engagement Frontier: Sophie Middleton

SNOWMASS-RP-FRONTIER@fnal.gov

1. SNOWMASS-RPF-01-HEAVY-QUARKS@FNAL.GOV
2. SNOWMASS-RPF-02-LIGHT-QUARKS@FNAL.GOV
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7. SNOWMASS-RPF-07-HADR-SPECT@FNAL.GOV

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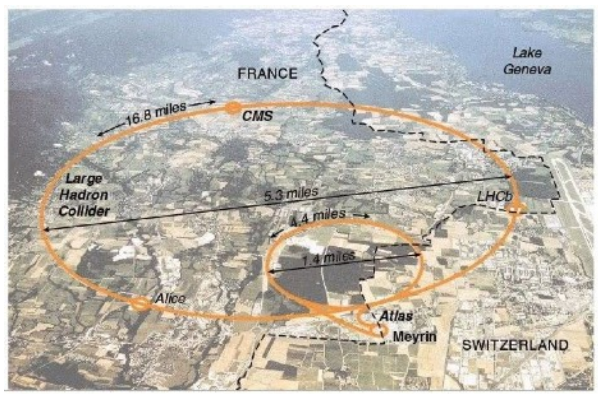
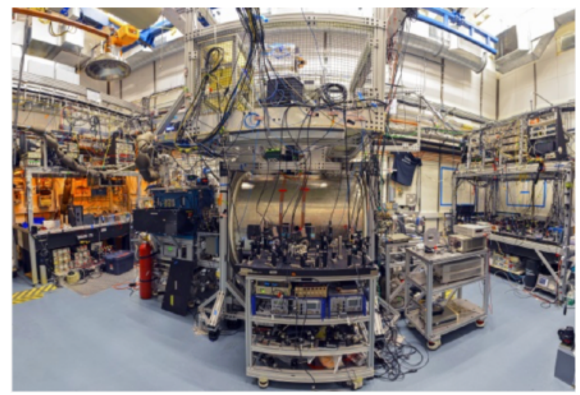


Accelerator-based experiments



“Table-top” experiments

Frontier summary: searches for new (rare) phenomena with precision measurements

RP Frontier goals

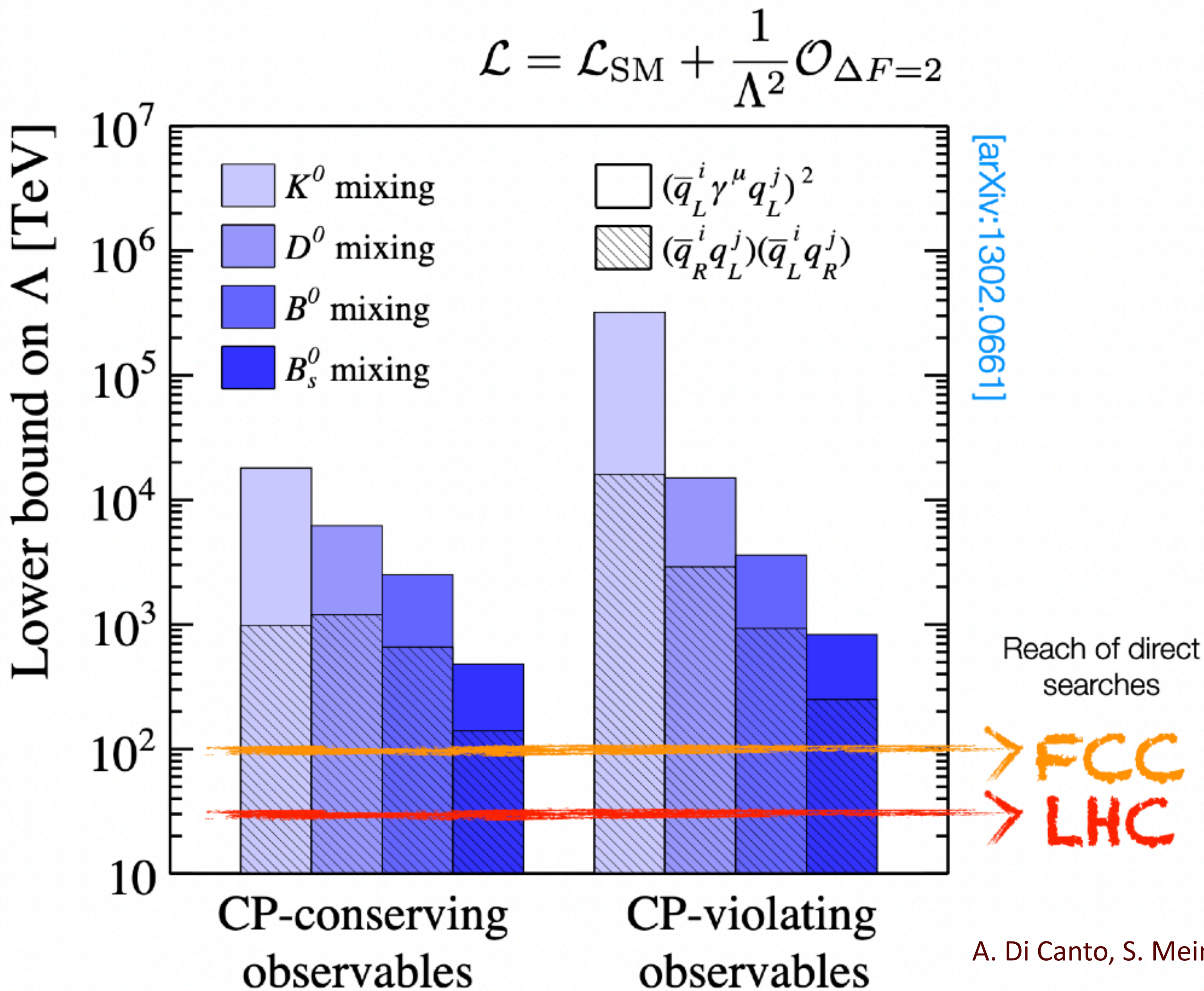
- Key phenomena addressed by the Frontier:
  - what is the nature of New Physics?
  - what is the nature of flavor?
  - what is the nature of Dark Matter?
  - what is the origin of matter-antimatter imbalance?
  - are there new symmetries of Nature?
  - are space-time symmetries of Nature broken?

- The experimental information can be obtained
  - from precision studies of low-energy observables
  - from transitions into invisible final states

- What theoretical precision is needed to reach conclusions?

Theoretical tools: perturbative QCD, EFTs, lattice, models

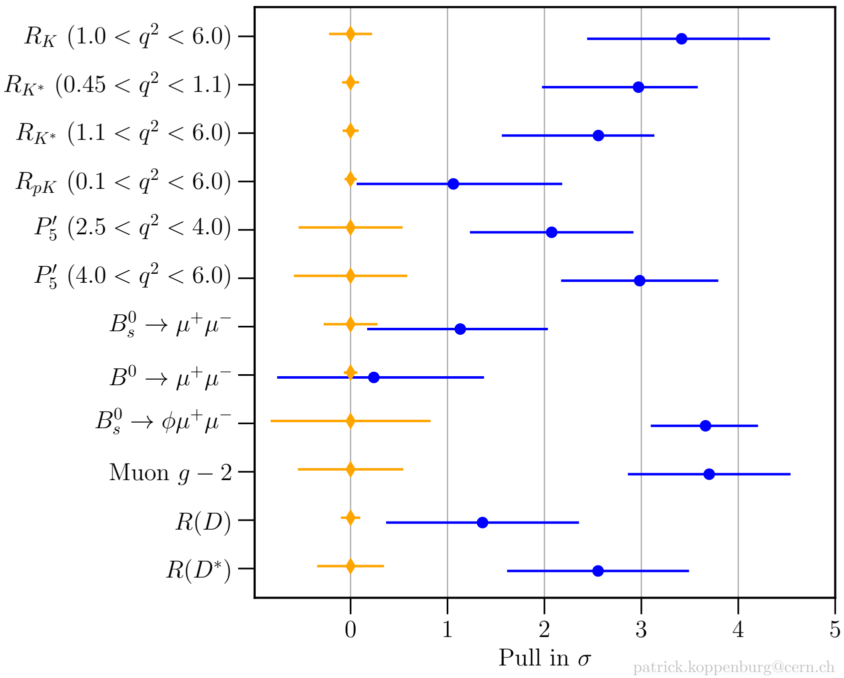
Reach of precision physics

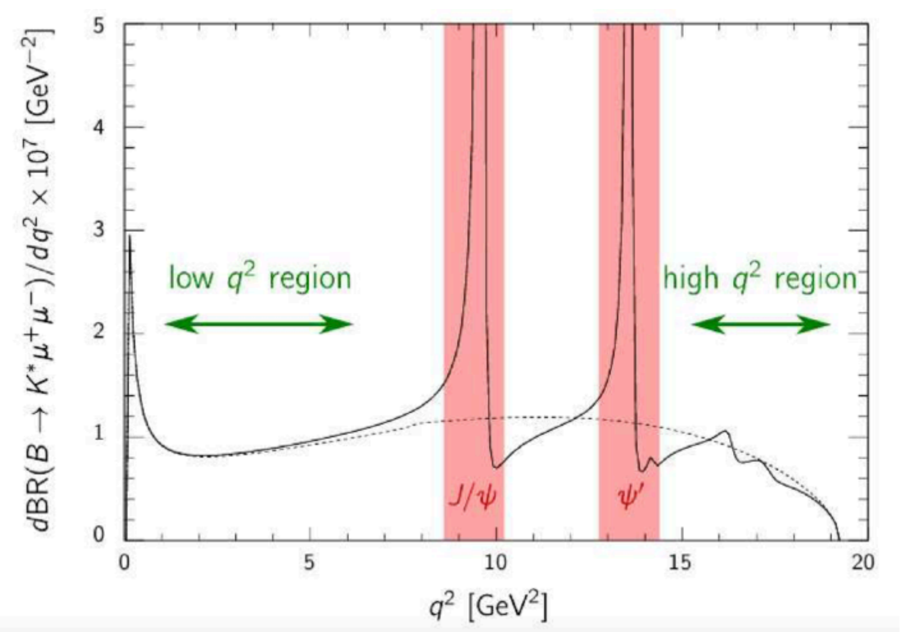


A. Di Canto, S. Meinel

Flavor anomalies and B-decays (RF1)

- Recent anomalies in electroweak rare B-decays (LHCb: CERN expts)
  - most mediated by quark-level $b \to s\ell^+\ell^-$ transitions, also $b \to c\ell\nu_\ell$



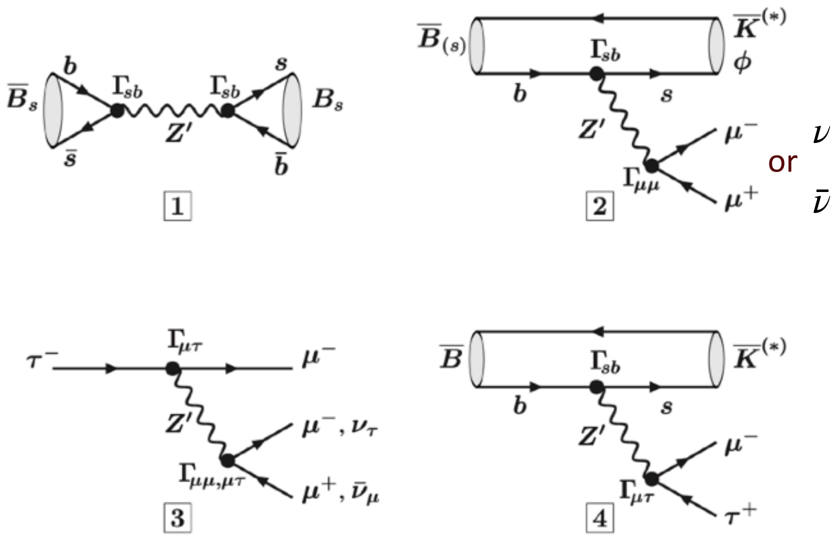


  - anomalies related to lepton-flavor universality (LFU) violations are not easy to explain by SM hadronic effects

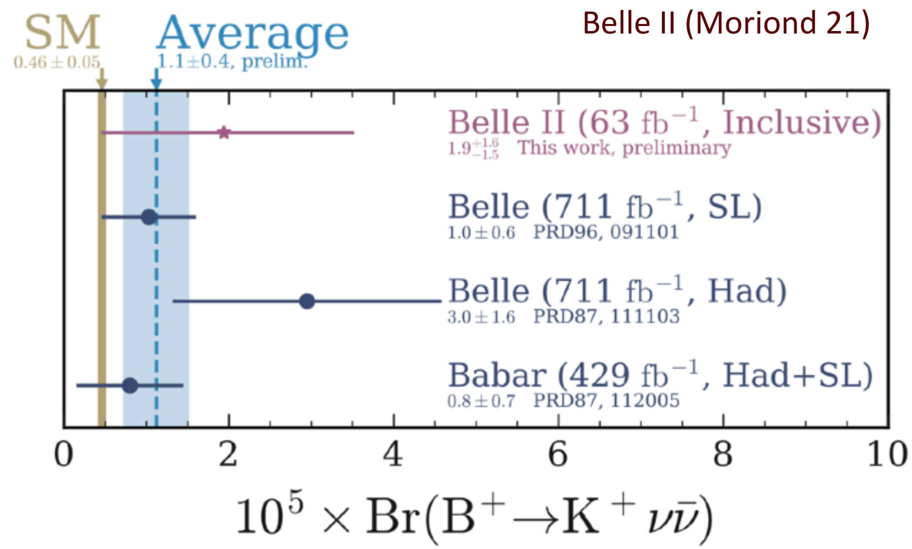
$$R_K = \frac{\mathrm{BR}(B \to K\mu^+\mu^-)}{\mathrm{BR}(B \to Ke^+e^-)}, \quad R_{K^*} = \frac{\mathrm{BR}(B \to K^*\mu^+\mu^-)}{\mathrm{BR}(B \to K^*e^+e^-)}$$

Need independent checks!

- Recent anomalies in electroweak rare B-decays (CERN expts)
  - most mediated quark-level $b \to s\ell^+\ell^-$ transitions, also $b \to c\ell\nu_\ell$
  - … if New Physics: can affect other transitions, like $b \to s\nu\bar{\nu}$?
  - … see in exclusive $B \to K^{(*)}\nu\bar{\nu}$ mode (Belle II)



Crivellin et al



Belle II (Moriond 21)

Maybe a 1σ excess?

  - $\nu\bar{\nu}$ final state is detected as missing energy: dark sector? $B^+ \to K^+ a$?

These measurements show complementarity of different flavor experiments

Complementarity of different heavy flavor experiments

LHCb

- Huge advantage in production rate, but large backgrounds results in lower efficiencies (advantage remains mostly for charged final states)
- Larger boost and superior decay-time resolution for time-dependent measurements
- Access to all *b*-hadron species

Belle II

- Cleaner environment allows for more generous selections — milder efficiency effects
- Unique access to fully neutral final states and decays with invisible particles
- Quantum-correlated $B\bar{B}$ production allows efficient determination of production flavor for time-dependent *CP*-violation measurements

ATLAS/CMS

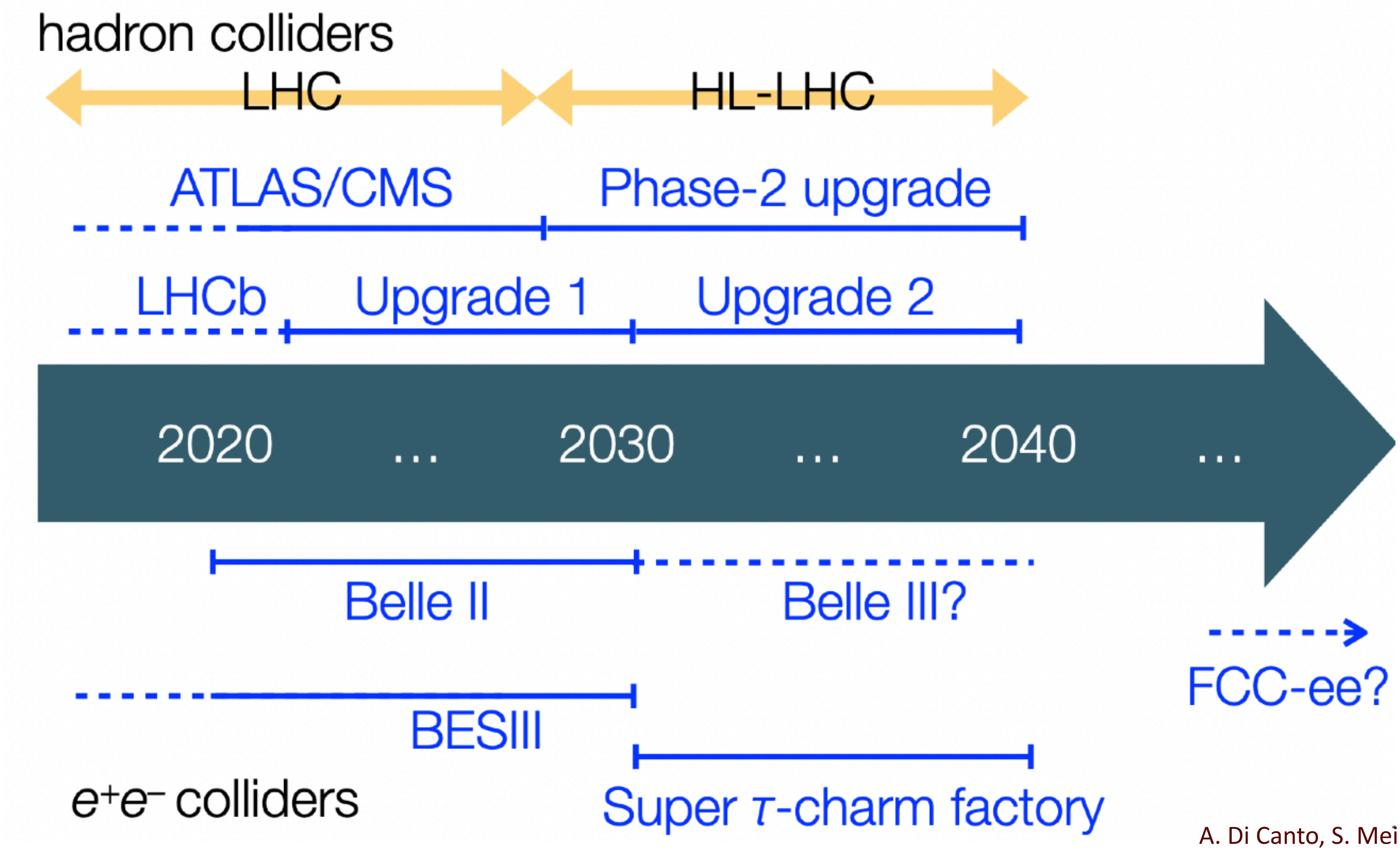
- Larger inst. lumi. than LHCb, access limited to final states with dimuons

charm-τ factories (BESIII/STCF)

- Unique access to quantum-correlated $D^0\bar{D}^0$ pairs

A. Di Canto, S. Meinel

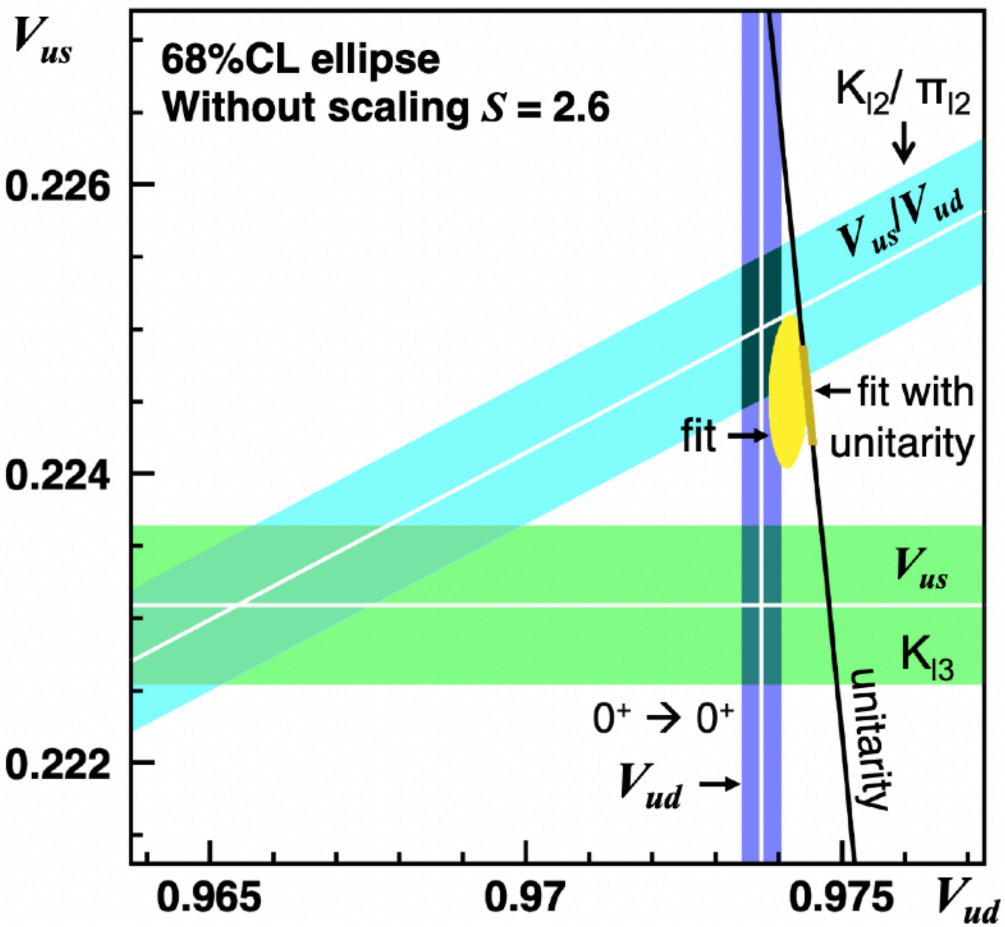
Timeline of heavy-flavor experiments (RF1)



A. Di Canto, S. Meinel

CKM first row unitarity problem (RF2)

- Recent discrepancy with CKM unitarity:



$|V_{ud}| = 0.97373(31)$
$|V_{us}| = 0.2231(6)$
$|V_{us}|/|V_{ud}| = 0.2311(5)$

Fit results, no constraint

$V_{ud} = 0.97365(30)$
$V_{us} = 0.22414(37)$
$\chi^2/\text{ndf} = 6.6/1\ (1.0\%)$
$\Delta_{CKM} = -0.0018(6)$
-2.7σ

$$|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 1 + \Delta_{CKM}$$

Negligible ~2x10^{-5} (B decays)

Broad sensitivity to BSM scenarios

E. Goudzovski, E. Passemar

How robust are theoretical extractions of V_{ud} and V_{us}?

Physics of light quark activities (RF2)

- RF2: precision measurements of kaon, hyperon, π^+ and $\eta^{(\prime)}$ decays.
  - ✓ CKM parameter measurements and unitary tests; symmetry tests; lepton flavor/number conservation tests; lepton universality tests.
  - ✓ Heavy new physics: sensitivity up to the PeV mass scale.
  - ✓ Hidden sectors: leading sensitivity below the GeV mass scale.
- Much experimental activity:
  - ✓ Ultra-rare kaon decays at NA62 and KOTO (+ future projects);
  - ✓ CPV in hyperon decays at BESIII (+ future super charm-tau factories);
  - ✓ kaon and hyperon decays at LHCb;
  - ✓ LFU and V_{ud} in pion decays at PIONEER;
  - ✓ Symmetry tests at η factories: JEF; REDTOP proposal.
- Significant advances in theory and lattice QCD: crucial for progress.

> Medium-scale initiatives (many centered in Europe and Asia): powerful physics insights, relatively short time scales, superb training opportunities, modest investment.

E. Goudzovski, E. Passemar

Anomalies and precision muon physics (RF3)

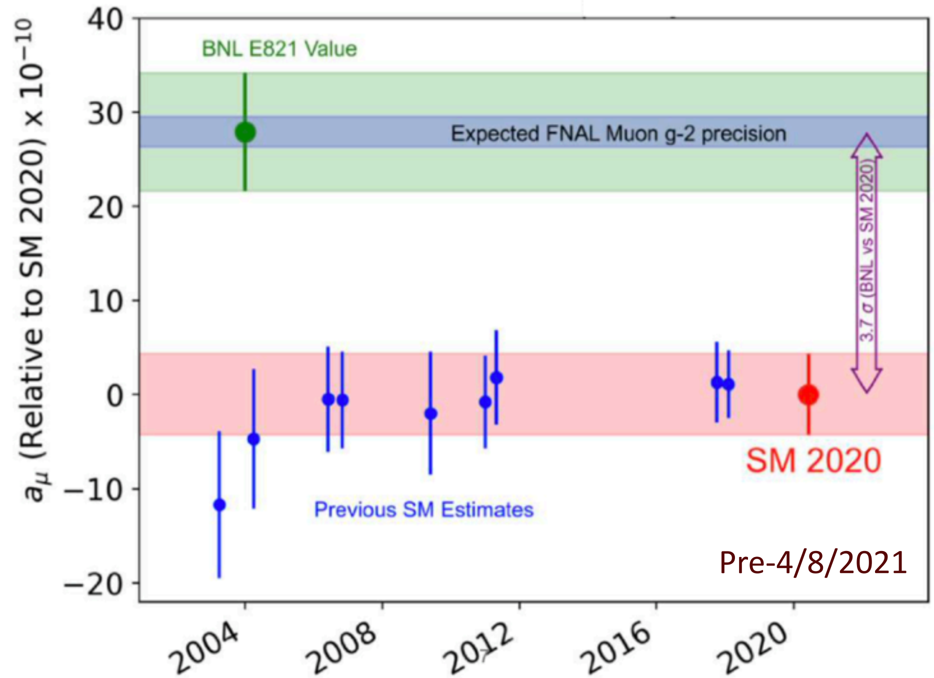
- Muon g-2: look for radiative corrections due to New Physics
  - magnetic moment: $\mathscr{H}_M = -\overrightarrow{\mu}\cdot\overrightarrow{B}$ with $\overrightarrow{\mu} = g\dfrac{e}{2m}\vec{s}$
  - in terms of form-factors: $a_\mu = \dfrac{g-2}{2} = F_2(0)$

$$\langle p_i|j^\mu|p_f\rangle = \overline{u}(p_i)\Gamma^\mu(P,q)u(p_f) = (-ie)\ \overline{u}(p_i)\left[F_1(q^2)\gamma^\mu + \frac{iF_2(q^2)}{2m}\sigma^{\mu\nu}q_\nu\right]u(p_f)$$

Contribution	Value $\times 10^{11}$
Experiment (E821)	116 592 089(63)
HVP LO (e^+e^-)	6931(40)
HVP NLO (e^+e^-)	−98.3(7)
HVP NNLO (e^+e^-)	12.4(1)
HVP LO (lattice, *udsc*)	7116(184)
HLbL (phenomenology)	92(19)
HLbL NLO (phenomenology)	2(1)
HLbL (lattice, *uds*)	79(35)
HLbL (phenomenology + lattice)	90(17)
QED	116 584 718.931(104)
Electroweak	153.6(1.0)
HVP (e^+e^-, LO + NLO + NNLO)	6845(40)
HLbL (phenomenology + lattice + NLO)	92(18)
Total SM Value	116 591 810(43)
Difference: $\Delta a_\mu := a_\mu^{\text{exp}} - a_\mu^{\text{SM}}$	279(76)

P. Winter (ANL)

arXiv: 2006.04822
https://muon-gm2- theory.illinois.edu/white-paper/



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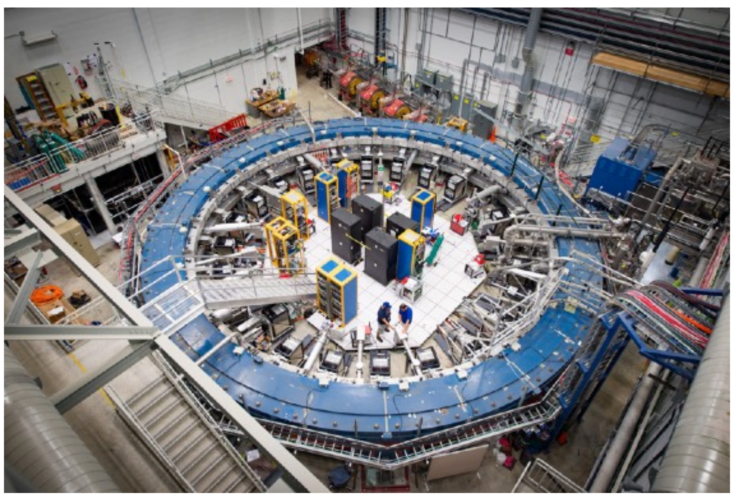
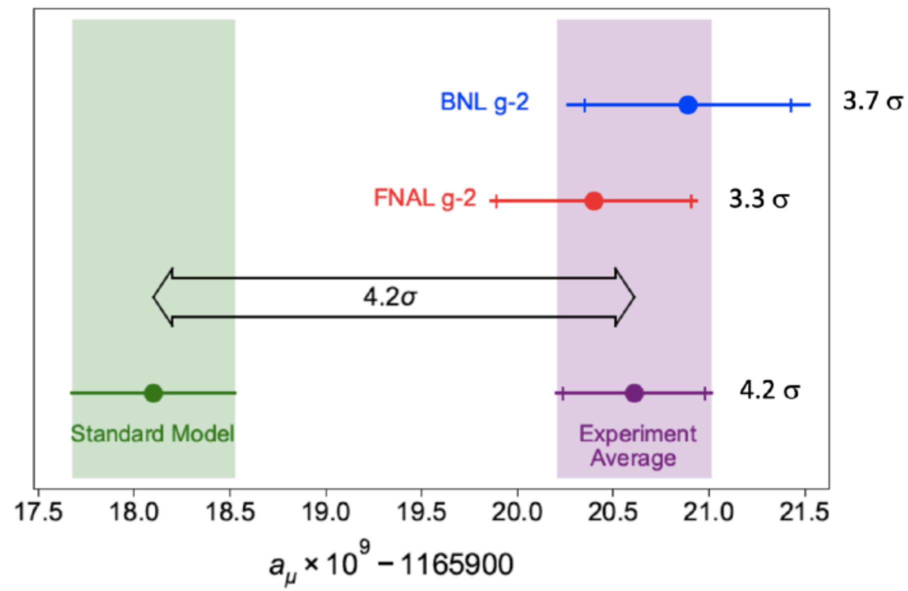




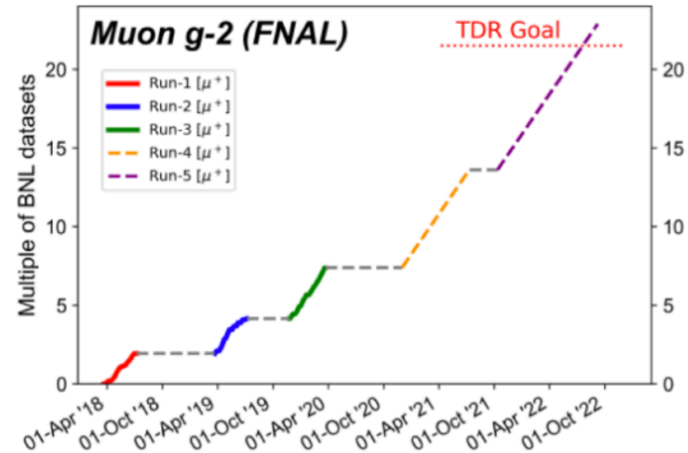
FNAL (g-2): $a_\mu(\mathrm{Exp}) = 116592061(41)\times 10^{-11}$

$a_\mu(\mathrm{Theory}) = 116591810(43)\times 10^{-11}$

$a_\mu(\mathrm{BMW}) = 116591954(55)\times 10^{-11}$

Outlook for muon g-2 experiments

MUON g-2 EXPERIMENTS STATUS AND OUTLOOK

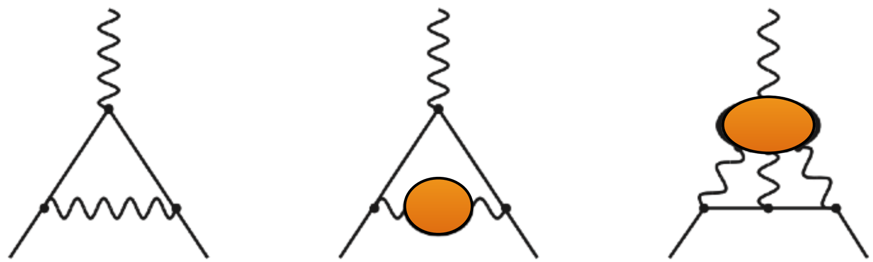


- Fermilab Muon g-2 E989 experiment:
  - Ongoing experiment, Runs 1-3 completed
  - First result (~BNL precision) this year
  - Run 4 and 5 will proceed
  - Prospects beyond that:
    - μ^- run (also good for CPT/LV tests)
    - More dedicated muon EDM
- J-PARC E34 g-2/EDM experiment:
  - A lot of ongoing R&D, not fully funded yet
  - Data taking maybe in a few years
  - One limitation is the muonium source (interest for other measurements)
- Muon g-2 theory:
  - Theory initiative will continue
  - Progress especially with LatticeQCD expected
  - Could bring us to 10σ with improved Muon g-2 experimental precision

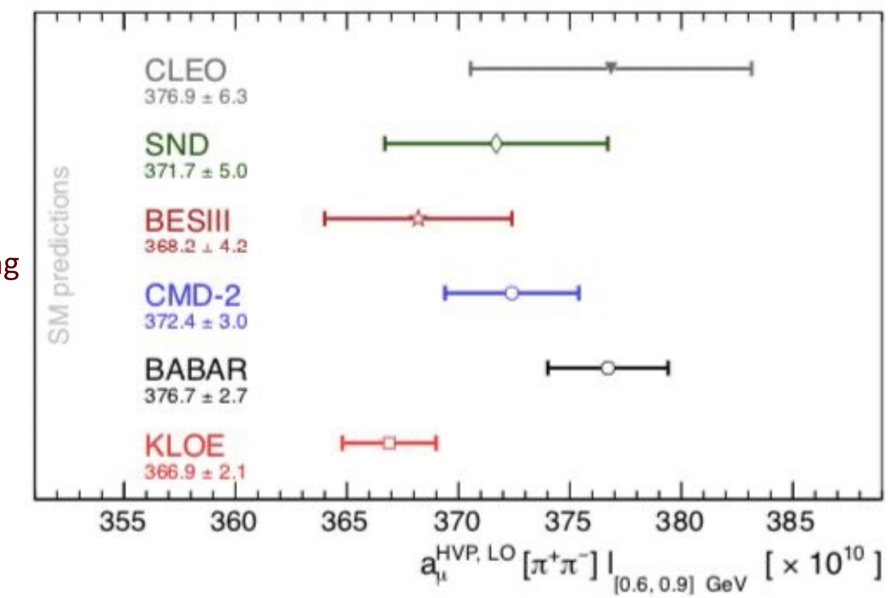
P. Winter (ANL)

Theoretical issues…

- Independent lattice computations of HVP
- Data-driven estimates of hadronic vacuum polarization (HVP)
  - discrepancy between KLOE and BaBar data used in HVP



Leading order   Vacuum polarization   Light-by-light scattering



$$a_\mu^{hvp} = \frac{1}{3}\left(\frac{\alpha}{\pi}\right)^2 \int_{4m_\pi^2}^{\infty} \frac{ds}{s} K(s) R(s)$$

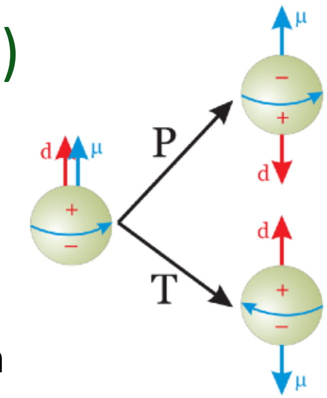
$$\frac{1}{12\pi} R(s) = \frac{1}{12\pi} \frac{\sigma(e^+e^- \to hadrons)}{\sigma(e^+e^- \to \mu^+\mu^-)}$$

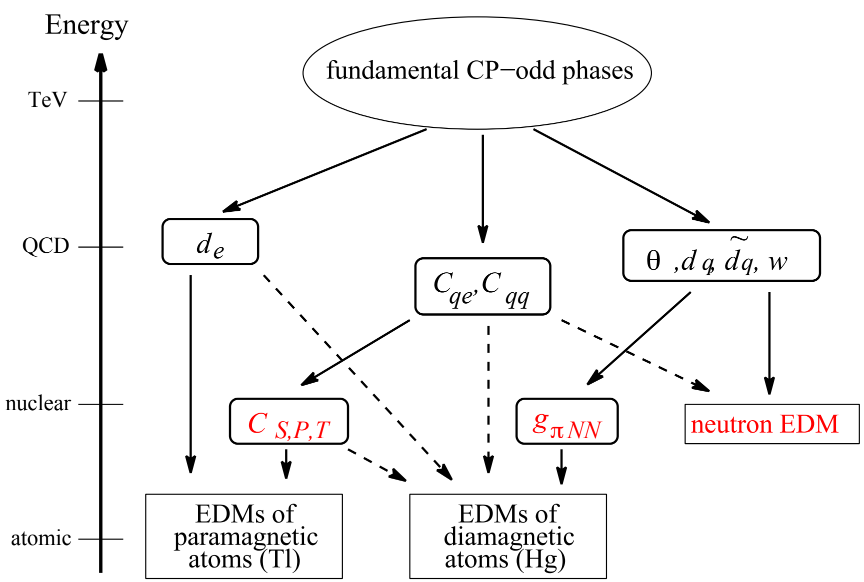
$$K(s) = \int_0^1 dx \frac{x^2(1-x)m_\mu^2}{x^2 m_\mu^2 + (1-x)s}$$

  - need radiative return Belle II data to eliminate the discrepancy
  - τ-decay data is not currently used: Belle II + lattice?

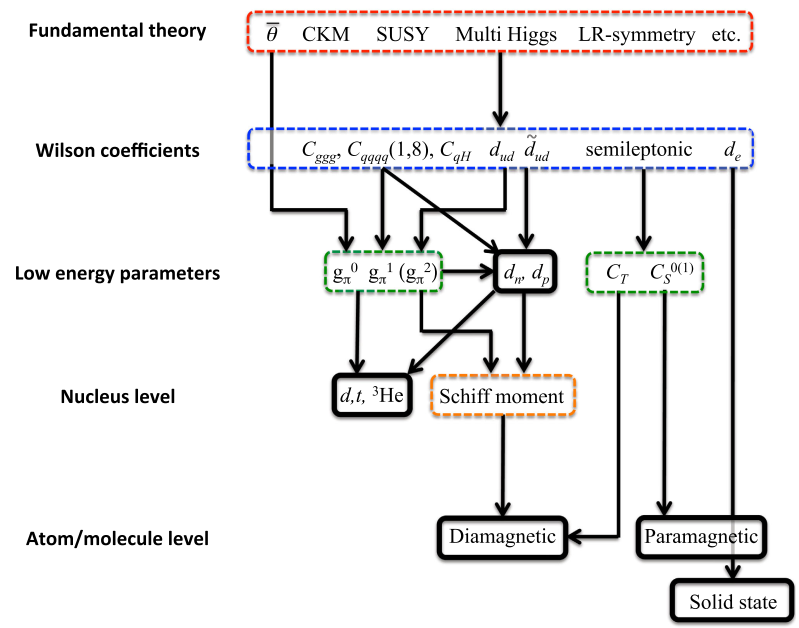
Discrete symmetries: Electric Dipole Moments (RF3)

- Studies of discrete symmetry breaking (C/P/CP/CPT)
  - probe BSM physics (a single source of CPV in the SM)
  - EDMs probe CP-violation
  - different systems sensitive to EDMs of different particles
    - paramagnetic atoms sensitive to (unpaired) electron edm
    - diamagnetic atoms sensitive to nucleus edm and less to e-edm





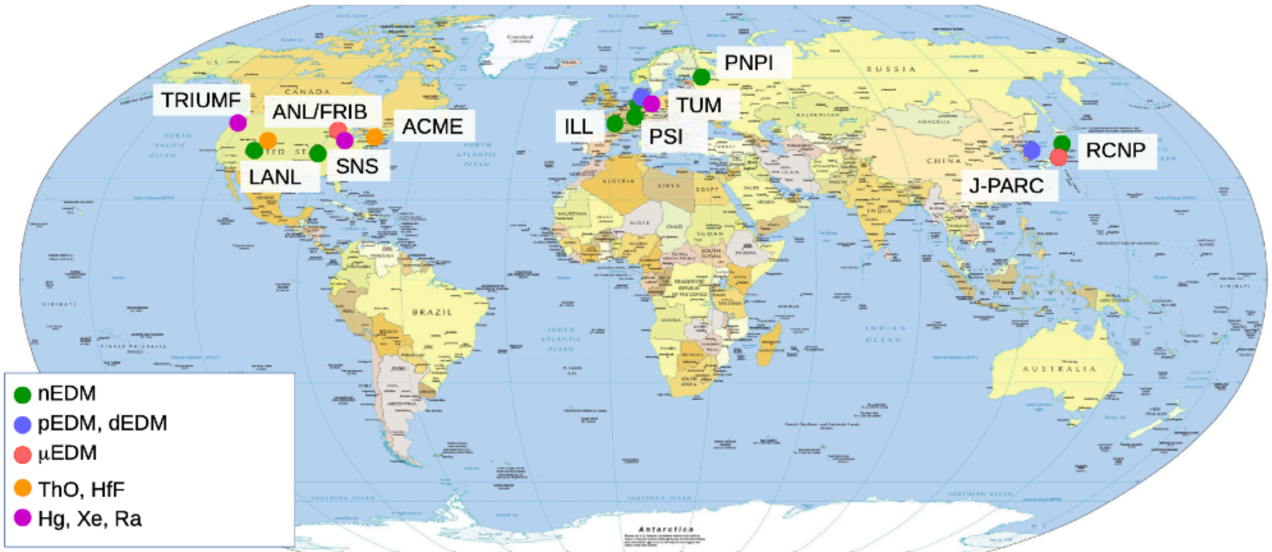
M. Pospelov and A. Ritz, Ann. Phys. 318 (2005) 119.



T. Chupp, et al, RMP 91(2019)

Discrete symmetries: EDM experiments (RF3)

- EDM measurements are done around the world
  - good prospects for improvement of current limits



	Current Limit	CKM prediction
e	10^{-29}	10^{-38}
μ	10^{-19}	10^{-35}
τ	10^{-16}	10^{-34}
n	10^{-26}	10^{-31}
p	10^{-23}	10^{-31}
^{199}Hg	10^{-29}	10^{-33}
^{129}Xe	10^{-27}	10^{-33}
^{225}Ra	10^{-23}	10^{-33}

experiment	sensitivity now	in 5 years	in 10 years
BaF (NleEDM) @ Groningen/Nikhef		1×10^{-30}	
HfF+ @ JILA	$1.3/1.64\times10^{-28}$	5×10^{-30}	5×10^{-31}
ThO (ACME) @ Yale	$1.1/1.64\times10^{-29}$	1×10^{-30}	
YBF @ Imperial	$1/1.64\times10^{-27}$	1×10^{-30}	1×10^{-31}

T. Blum (UConn)

Lorentz and CPT-symmetry tests (RF3)

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

T. Blum, P. Winter

Baryon and lepton number violation (RF4)

This Topical Group will address the following topics:

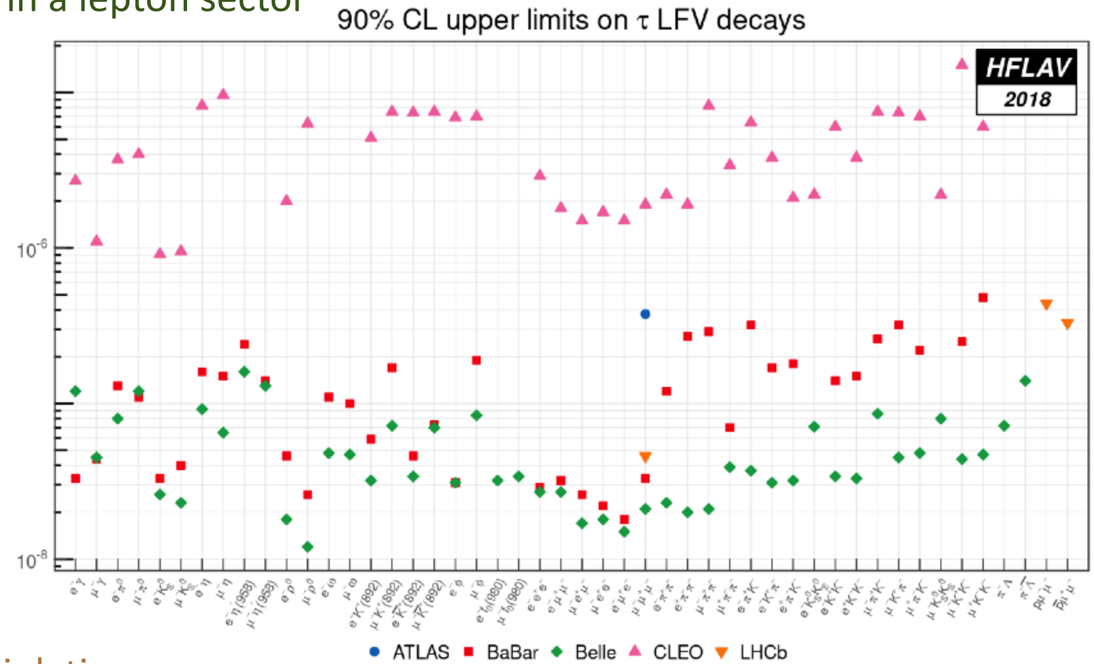
1. Theories for baryon and lepton number violation: *P. Fileviez Perez (CWRU), M.B. Wise (Caltech)*
2. Neutrinoless double beta decays: *V. Cirigliano (LANL), A. Pocar (UMass)*
3. Baryon and Lepton number violation at colliders: *R. Ruiz (Cracow, INP), E. Thomson (UPenn)*
4. Proton decay: *E. Kearns (Boston Univ.), S. Raby (Ohio State Univ.)*
5. n-nbar oscillations: *K. Babu (OSU), L. Broussard (ORNL)*
6. More exotic L and B violating processes: *S. Gardner(Univ. of Kentucky), J. Heeck (Univ. of Virginia)*
7. Connections to Cosmology: *A. Long (Rice Univ.), C. Wagner (Univ. of Chicago/ANL)*

Precision lepton physics (RF5)

★ Why study flavor-changing neutral currents (FCNC)?

★ No basic FCNC vertices in the Standard Model: sensitive NP tests

★ Resurgence of experimental studies in a lepton sector



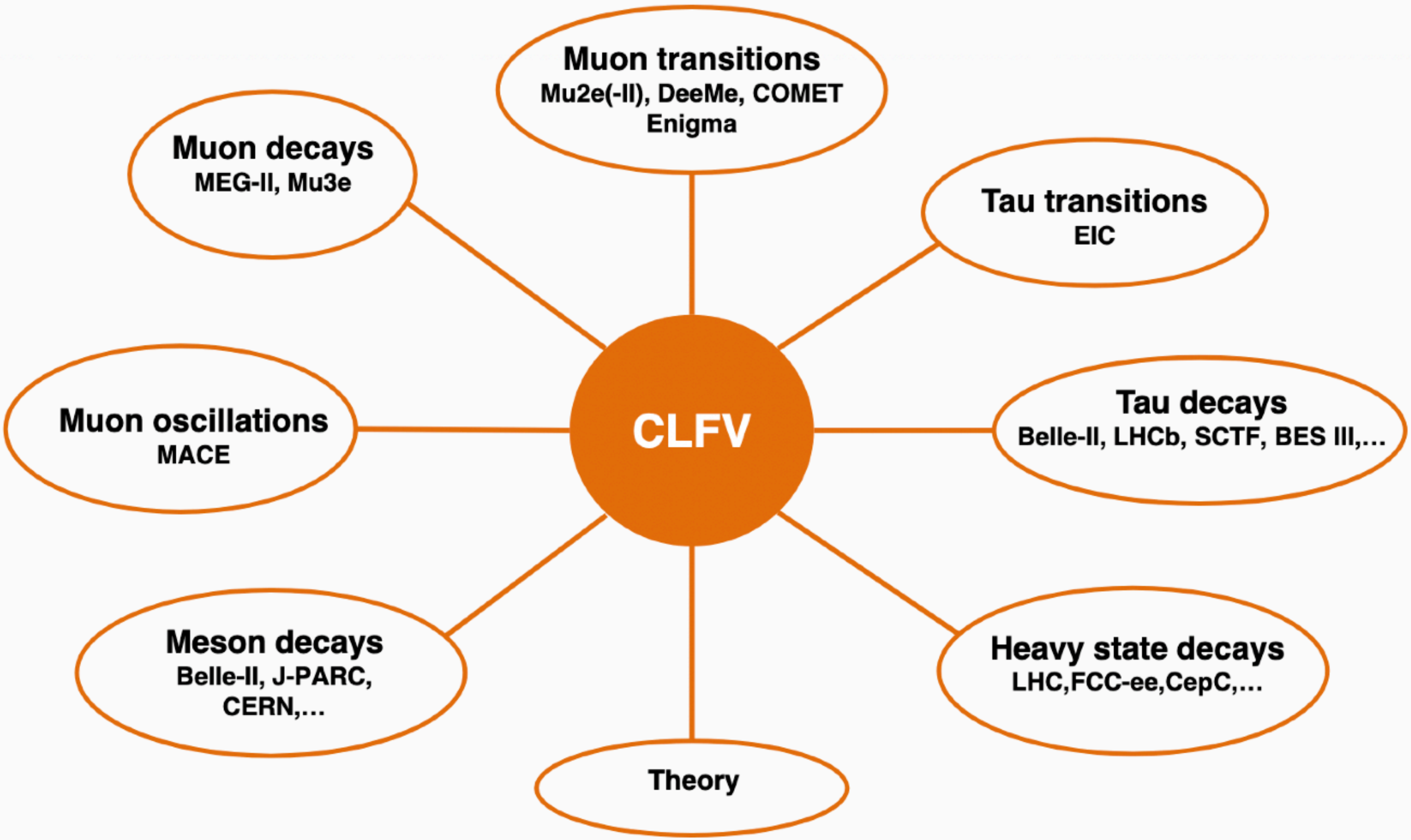
- lepton-flavor violating processes
  - $\mu \to e\gamma$, $\tau \to e\gamma$, etc.
  - $\mu \to eee$, $\tau \to \mu ee$, etc.
  - $\mu^+ e^- \to e^- \mu^+$
  - $Z^0 \to \mu e$, τe, etc.
  - $H \to \mu e$, τe, etc.
  - K^0 (B^0, D^0, ...) $\to \mu e$, τe, etc.
  - K^+ (B^+, D^+, ...) $\to \pi^+ \mu e$, $\pi^+ \tau e$, etc.
  - $\mu^- + (A, Z) \to e^- + (A, Z)$
  - $e^- + (A, Z) \to \mu^-/\tau^- + (A, Z)$

- lepton number and lepton-flavor violating processes
  - $(A, Z) \to (A, Z\pm2) + e^\mp e^\mp$
  - $\mu^- + (A, Z) \to e^+ + (A, Z-2)$

★ Highly suppressed in the Standard Model, e.g. $Br(\mu \to e\gamma) = \frac{3\alpha}{32\pi}\left|\sum_i U^*_{\mu i} U_{ei} \frac{m^2_{\nu_i}}{M^2_W}\right|^2 < 10^{-54}$

Exp: new muon facilities. Theo: EFT computations of nuclear effects

Charged lepton flavor violation (RF5)



B. Echenard, S. Davidson

Possibilities for future muon experiments at FNAL (RF5)

PIP II

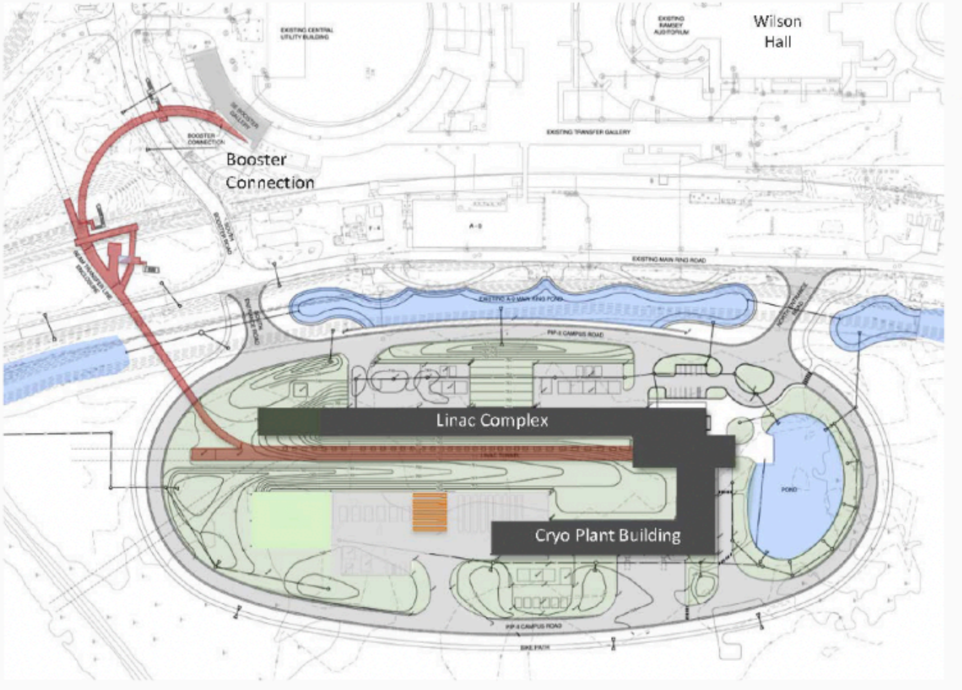
800 MeV H− linac
- Up 165 MHz bunches
- Up to 2 mA CW
- Up 1.6 MW

Upgraded Booster
- 20 Hz, 800 MeV injection
- New injection area

Upgraded Recycler & Main Injector
- RF in both rings

Groundbreaking for project
- March 2019

Protons for the High Energy Program
- ~1% of available beam!



PIP-II will deliver 1.2 MW proton beam for LBNF, but that program uses a very small fraction of the available beam → opportunity for new muon experiments

Advanced muon facility at FNAL (RF5)

The Advanced Muon Facility (AMF) is a new facility for the next generation of muon experiments at FNAL with the PIP-II accelerator.

This complex would provide **the world's most intense positive and negative muon beam**, and enable a suite of experiments, including

- CLFV in muon decay and transitions
- Muonium-antimuonium oscillations
- Muon EDM
- Muon spin rotation

and potential synergies with the development of a muon collider and a dark matter program

A beam for a next generation muon conversion experiment

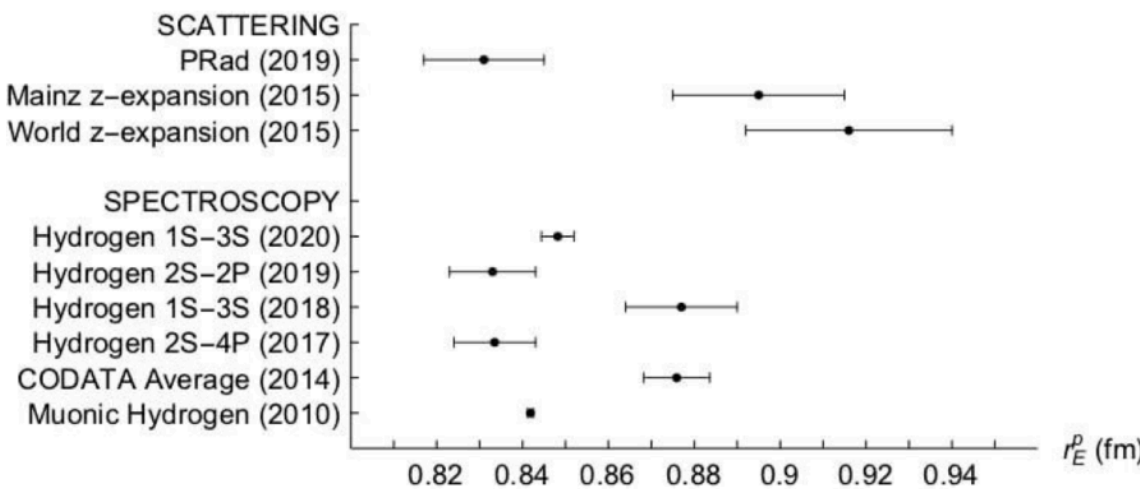
- **Probe R_{me} sensitivity down to 10^{-19}**, with the ultimate objective to reach 10^{-20} and probe $O(10^4 - 10^5)$ TeV effective mass scale
- **Probe high-Z target** (e.g. Au) to explore underlying new physics if CLFV is observed
- Based on the PRISM concept to provide a low momentum, quasi-mono-energetic muons beam with extremely low pion contamination

A New Charged Lepton Flavor Violation Program at Fermilab (B. Echenard et al. – 2203.08278)
Design Considerations for FNAL Multi-MW Proton Facility in the DUNE/LBNF era (J. Eldred at al – 2203.08267)

Other topics: QCD vs New Physics

- Proton's radius from muonic hydrogen: any New Physics?

★ Level splittings (e.g. Lamb shift) are sensitive to the charge radius of the proton



★ They are also sensitive to QED radiative corrections

★ Are there possible light New Physics particles that are responsible for this difference?

Barger et al, PRL 106 (2011) 153001

Remove proton radius issue from the problem: atomic physics with muonium?

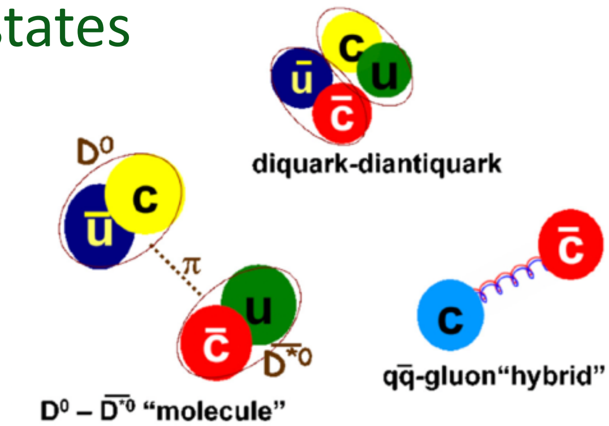
Dark Sector studies (RF6)

A non exhaustive list of topics:

- Comprehensive theory motivations for dark sectors;
- Discussion of simplified & benchmarks models for dark sectors;
- Discussion of experimental targets;
- Study of more complete theories and their connection to DM cosmology (thermal freeze-out, freeze-in, strongly interacting DM, …);
  Interesting recent developments here!
- Filling the gaps in theory simulations/calculations.
  E.g. utilize secondary beams of SM particles produced in beam dumps to probe dark sectors.

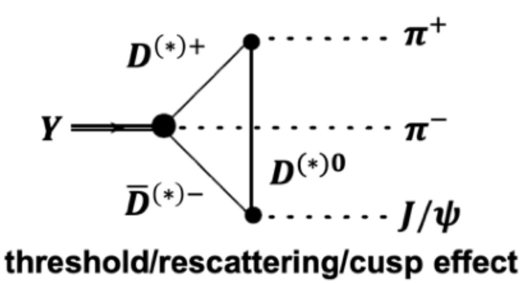
S. Gori

- Recent experiments: multitude of new states
  - many cannot be explained as $q\bar{q}$ states
  - most in the heavy quark sector (e.g., X(3872))
    - 54 observed exotics (incl pentaquarks)
      - 44 charmonium-like
      - 5 containing b-quark
      - 1 with a signle b-quark (bsud)
  - 15 states confirmed at included in the PDG
  - many more to be discovered!
- What are they? Molecules? Hybrids? …
  - Quantum Mechanics: mixed
  - theoretical description: models, lattice?
  - relation to fundamental QCD phenomena



S. Godfrey and S. Olsen,
Ann. Rev. Nucl. Part. Sci. 58 (2008) 51

or



T. Skwarnicki, R. Lebed

Directions for Theory for the 2020's

- The kinds of analysis required by the flood of experimental data that will emerge in the next few years will require broader theoretical efforts:
  - Collaborative endeavors by theorists with differing areas of expertise,
    e.g., lattice simulations and potential models
    e.g., effective field theory and scattering theory
    e.g., medium-energy nuclear theorists and high-energy flavor theorists
  - Collaborative endeavors by theorists working closely with particular experiments
    e.g., JPAC [Joint Physics Analysis Center] with connections to GlueX

R. Lebed

Things to take home

- Flavor physics is a very exciting field at the moment
  - B-physics: CKM measurements and B-mixing to constrain NP
  - B-physics anomalies: first glimpse of New Physics or not?
  - Charm physics: CP-violation with up-type quarks (LHCb/Belle II)
  - Lepton flavor physics: bright future (Mu2e/COMET $\rightarrow$ muon collider)?
  - The most promising hints of new physics from the LHC are from flavor
- EDMs provide powerful probes of New Physics with more reach than direct searches and provide complimentary information
  - electron EDM down to 10^{-31} e-cm in 10 years
- Magnetic dipole moments (electron, muon) have research timelines that span the next decade
  - muon g-2 results might help to clarify the path forward
- Precise tests of SM in parity violation ongoing (JLab, Mainz)
- AMO techniques help probe the whole spectrum of BSM physics
- Precision hadron spectroscopy: new phenomena in QCD


The Evening Herald
EXTRA!

Effective Lagrangians and CP-violation

$$\mathcal{L}_{\rm CPV}^{d\leq 6} = -\frac{g_s^2}{32\pi^2}\bar{\theta} G\tilde{G}$$ dim=4 QCD θ-term

$$- \frac{i}{2}\sum_{q=u,d,s} d_q \bar{q}(\sigma\cdot F)\gamma_5 q$$ dim=5 Quark EDM (qEDM)

$$- \frac{i}{2}\sum_{q=u,d,s} \tilde{d}_q g_s \bar{q}(\sigma\cdot G)\gamma_5 q$$ dim=5 Quark Chromo EDM (CEDM)

$$+ d_w \frac{g_s}{6} G\tilde{G}G$$ dim=6 Weinberg's 3g operator

$$+ \sum_i C_i^{(4q)} O_i^{(4q)}$$ dim=6 Four-quark operators

B. Yoon

LOI Breakdown

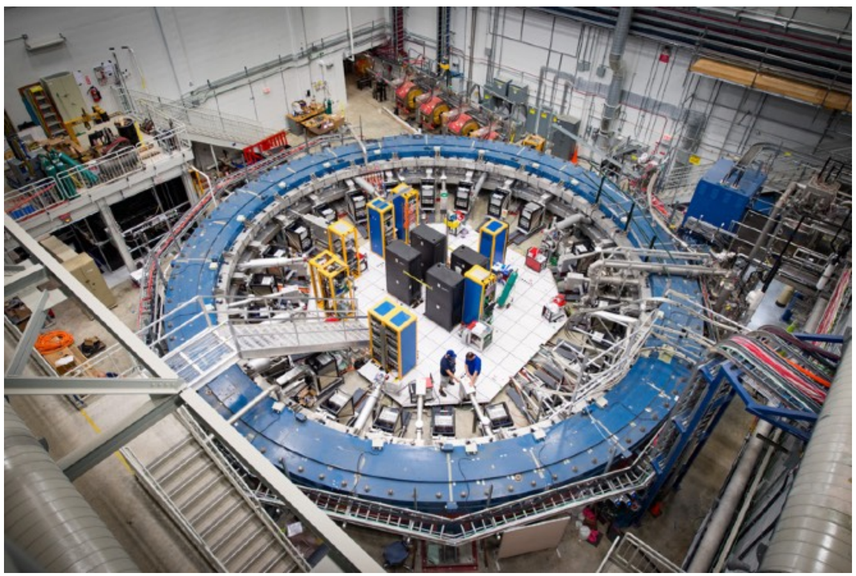
"Fundamental" Physics	
Dedicated Experiment Exploring Gravitational Effects on CP Violation	Gravity-generated / connected CPV
Strong CP and Neutrino Masses: A Common Origin of Two Small Scales	neutron EDM <-> neutrino masses (cross-frontier)
Searches for Exotic Short-range Gravity and Weakly Coupled Spin-Dependent Interactions using Slow Neutrons	Gravity tests with neutrons
Lorentz and CPT Tests with Low-Energy Precision Experiments	L / CPT tests (overview of many opportunities)
NOPTREX:	T violation with neutrons
Muonium Gravity Experiment	Gravity test (antimatter)
Facilities	
Upgraded Low-Energy Muon Facility at Fermilab	Facility (cross-group)
Potential storage ring and Muon Campus experiments	Muon campus / facility use
Dipole Moments	
Using lattice QCD for the hadronic contributions to the muon g – 2	Lattice QCD - HVP
Calculations of nucleon electric dipole moments on a lattice with chiral fermions	Lattice QCD - nucleon EDM
Hadronic contributions to the anomalous magnetic moment of the muon	Lattice QCD - HVP & HLbL
Opportunities and New Physics Implications for (g – 2)e,μ	electron and muon MDM: Theory model (cross frontier)
The Proton Storage Ring EDM Experiment	EDMs (CPV) and axion DM
Test of the Standard Model and Search for Physics Beyond⁎ Opportunities for Fundamental Physics using Small-scale Storage Ring Experiments	EDMs storage ring (see other LOI in AF5)

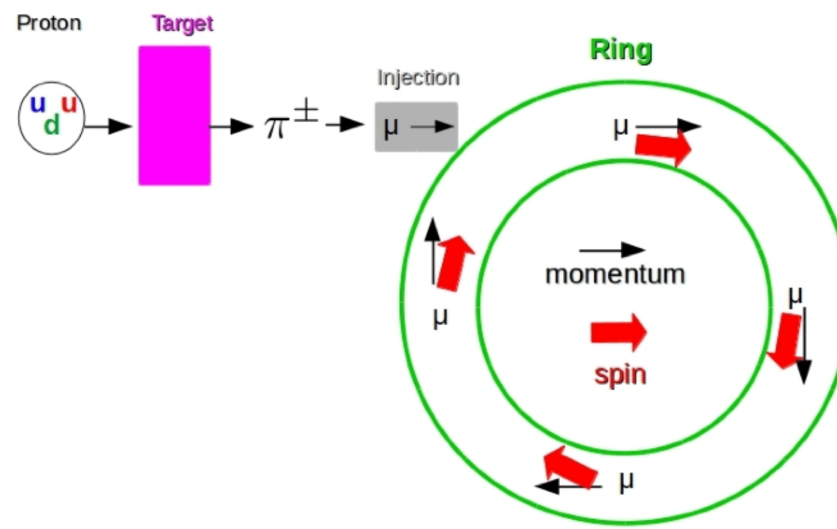
AMO	
Atomic/nuclear clocks and precision spectroscopy measurements for dark matter	Precision clocks and spectroscopy/DM
Optically levitated sensors for precision tests of fundamental physics	Gravity tests (micron-scale) with nanospheres, axion DM
Probing fundamental physics with highly-coherent nuclear spins	EDM (CPV) and axion DM
Th-229 Nuclear Clock	Precision clocks
Mechanical tests of the gravity-quantum interface	Gravity (-quantum) tests
Doped Cryocrystals for Ultrasensitive EDM Measurements: Snowmass LOI	EDMs, facility for cryo-crystals
Searches for new sources of CP violation using molecules as quantum sensors	EDMs (CPV) with molecules

R. Bernstein (FNAL)

Muons: examples of current puzzles

- Muon's magnetic properties: a = (g-2)/2: $\vec{\mu} = g\frac{e}{2m}\vec{s}$
    - there is a >3 sigma discrepancy between the theoretical prediction and exp. measurement





Lindner et al

Are there possible heavy New Physics particles that are responsible for this difference?

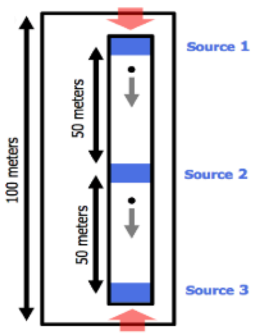
Other BSM searches with AMO

Atom interferometry

BSM searches:
Variation of fundamental constants
Ultralight scalar DM & relaxion searches
Violation of the equivalence principle

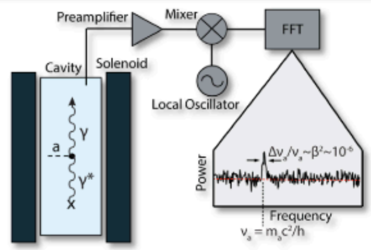
Prototype gravitational wave detectors

MAGIS-100 Fermilab



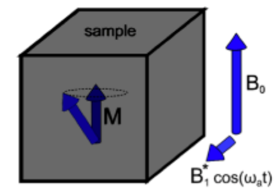
MIGA (France), 150 meters under construction
AION

Axion and ALPs searches



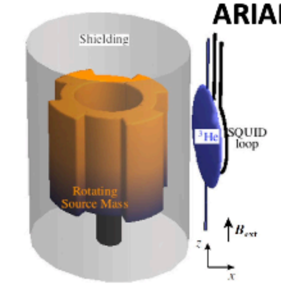
Microwave cavities: HAYSTAC
AMO: measurements beyond quantum limits

CASPEr-electric, solids
(coupling to gluons)



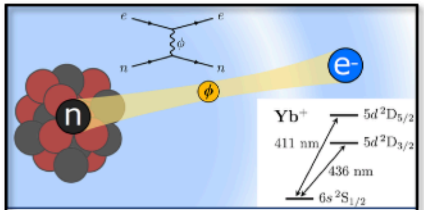
CASPEr-wind, Xe
(coupling to fermions)

ARIADNE



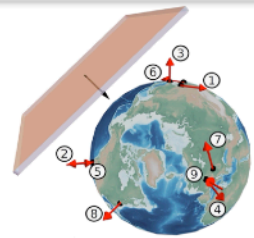
Resonantly detecting axion-mediated forces with NMR

Other dark matter & new force searches



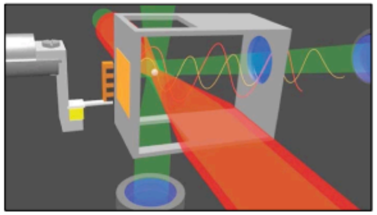
Fifth force searches with precision spectroscopy with atoms and ions

WReSL: Cs spectroscopy



GNOME: network of optical magnetometers for exotic physics

Levitated optomechanics

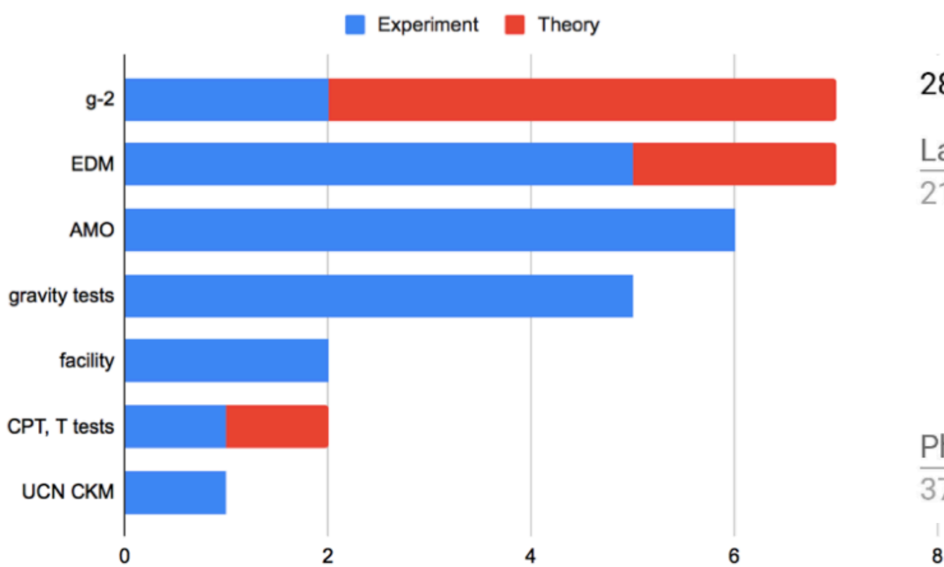


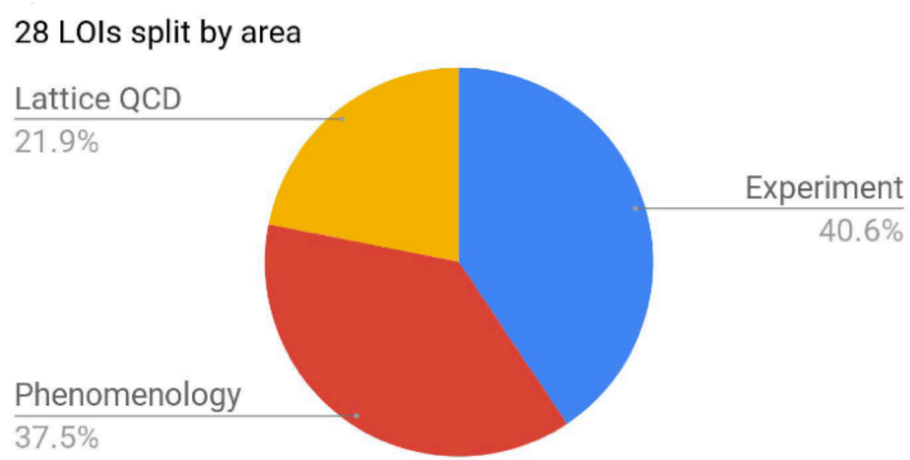
Also: gravitational wave detection and testing the Newtonian inverse square law

Many other current & future experiments: HUNTER (AMO sterile neutrino search), SHAFT, ORGAN & UPLOAD (axions), solid-state directional detection with NV centers (WIMPs), doped cryocrystals for EDMs, Rydberg atoms, tests of the gravity-quantum interface, tests of QED, … See Rev. Mod. Phys. 90, 025008 (2018) for a recent review.

Marianna Safronova (UDel)

- 214 LOIs submitted to RPF
  - physics, devices/experiments, facilities
  - example distribution for RF3-5 and RF1:





  - exploration of recent experimental (flavor) anomalies: New Physics nearby?
  - LOIs: RF1: 28 RF2: 8, RF4: 31, RF5: 9

Community input

Letters of Interest (submission period: April 1, 2020 – August 31, 2020)

Letters of interest allow Snowmass conveners to see what proposals to expect and to encourage the community to begin studying them. They helped conveners to prepare the Snowmass Planning Meeting that took place on October 5 - 8, 2020 ~~at Fermilab~~ on Zoom. Letters should give brief descriptions of the proposal and cite the relevant papers to study. Instructions for submitting letters are available at https://snowmass21.org/loi. Authors of the letters are encouraged to submit a full writeup for their work as a contributed paper.

Contributed Papers (submission period: April 1, 2020 – March 15, 2022)

Contributed papers will be part of the Snowmass proceedings. They may include white papers on specific scientific areas, technical articles presenting new results on relevant physics topics, and reasoned expressions of physics priorities, including those related to community involvement. These papers and discussions throughout the Snowmass process will help shape the long-term strategy of particle physics in the U.S. Contributed papers will remain part of the permanent record of Snowmass 2021. Instructions for submitting contributed papers are available at https://snowmass21.org/submissions/ (both solicited and non-solicited)

Final Product: Snowmass Report (submission: 30 September 2022)

The Town Hall meeting was held in response to Letters of Interest (LOIs) submitted to our Frontier. It offered the submitters of LOIs a chance to make presentations on the topic of their LOIs.