Rare and Precision Frontier: Status and Goals

R. Bernstein (FNAL)
Marina Artuso (Syracuse), Alexey Petrov (Wayne State)
for the Frontier

The Rare and Precision Frontier

- *Origin of Flavor, Generations, and the Mass Hierarchy*
  - why flavors and generations? a unique window into new physics
- *The physics of the dark sector available at high-intensity machines*
  - well-motivated and powerful, timely probes
- *Origin of the fundamental symmetries and their breakdown mechanisms*
  - Baryon and Lepton Number Violation; EDMs and CP; fundamental (e.g. Lorentz) symmetry tests
- *Hadron Spectroscopy:*
  - develop a deeper understanding of non-perturbative QCD using the rich landscape of conventional and exotic hadrons

The Rare and Precision Frontier (2)

- *Theory that guides and enables such experiments*
  - especially EFTs and lattice
- *Experiments:*
  - using precise measurements and/or rare processes to search for new physics
  - such as muon g-2, CKM tests, *B* anomalies, EDMs, and CP violation

The Experimental Landscape

	Physics Driver
1	New physics in flavor/flavor problem
2	Probes of spacetime symmetries and gravity
3	Electric Dipole Moments
4	Baryon-lepton number violation
5	Charged Lepton Flavor Violation
6	Dark Sector Probe
7	QCD at work in hadron spectroscopy

Experiment	Status	Time Scale	Driver
LHCb, LHCb Upgrade 2 [ATLAS, CMS for some modes]	LHCb U2 now in CERN baseline program	Now-midterm	1,2,6,7
Belle II and its upgrades		Now-midterm	1,2,6,7
BESIII/STCF		Now-midterm	1,2,6,7
FCCee/CEPC	Proposed	Post HL-LHC	1,2,6,7
Rare K decay experiments	Now/proposed	Now-midterm	2
η,η' factories	Now/proposed	2030's	1
N-Nbar, MAGE, table-top experiments on quantum-gravity interface	Proposed	late 2020's-2030's	2,4
Storage ring EDMs	Proposed	2030-2040	1,2,3,6
Rare muon decay experiments/ Mu2e-II+advanced muon facility at FNAL	Now/proposed	2030-2040	4,5,6
Dark Matter New Initiative	Proposed	late 2020's	6

Frontier-Wide Issues

- New P5 Driver:
  - physics of flavor and generations
    - why are generations? why three? are there more?
      - we have not understood the reason for generations since the discovery of the muon!
    - what is the origin of flavor?
    - *a common theme across much of the Frontier*
- Much of the frontier is “small” and “medium” experiments
  - these must thrive in US ecosystem
    - smaller experiments and efforts provide unique training for early career researchers — good for Frontier and for all of HEP

Major Meetings

- Colloquium I: Wed 7/20 2-3:30 (simultaneous with neutrino colloquium)
    - Stefania Gori: Understanding Dark Matter and Dark Sectors at the RPF
    - Round table with Marianna Safronova, Nick Hutzler, On Kim, Tanmoy Bhattacharya: "Complementarity and synergies between HEP and AMO in EDM experiments and other precision tests"
- Colloquium II: Thurs 7/21 2-3:30
    - Phil Urquijo: "SM precision tests, and new physics in heavy flavor: examples from the RP Frontier"
    - Vincenzo Cirigliano: "Search for New Physics: the questions we can address with leptons and quarks"
- RPF Frontier-Wide Discussion: Tues 7/19 8AM (for overall report)
    - this talk is essentially an outline of report themes — come and tell us what you think!

Structure of This Talk

- We asked all Topical Groups to provide:
  - Major Physics Questions
  - Status and Plans for Snowmass
  - What we want P5 to recommend and for DOE to support
- Our plan for Snowmass is for further community input at the meetings and to the draft white papers on the topics discussed in this talk
- Leading to Frontier report after Snowmass

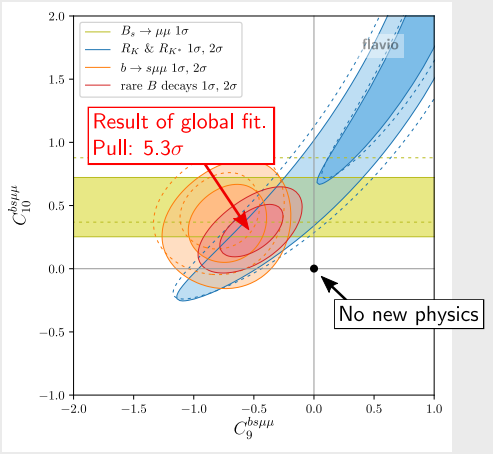
How to Participate

- Come to the meetings
  - will name some key meetings throughout, but no one can go to all of them. Included those especially recommended by sub-conveners
- Go to Overleaf links
  - many of you have been involved in writing these, but we give explicit links here.
- Contact sub-conveners or conveners
  - email list on Snowmass web and in backup slide

Weak Decays of *b* and *c*

Angelo Di Canto (BNL), Stefan Meinel (U Arizona)

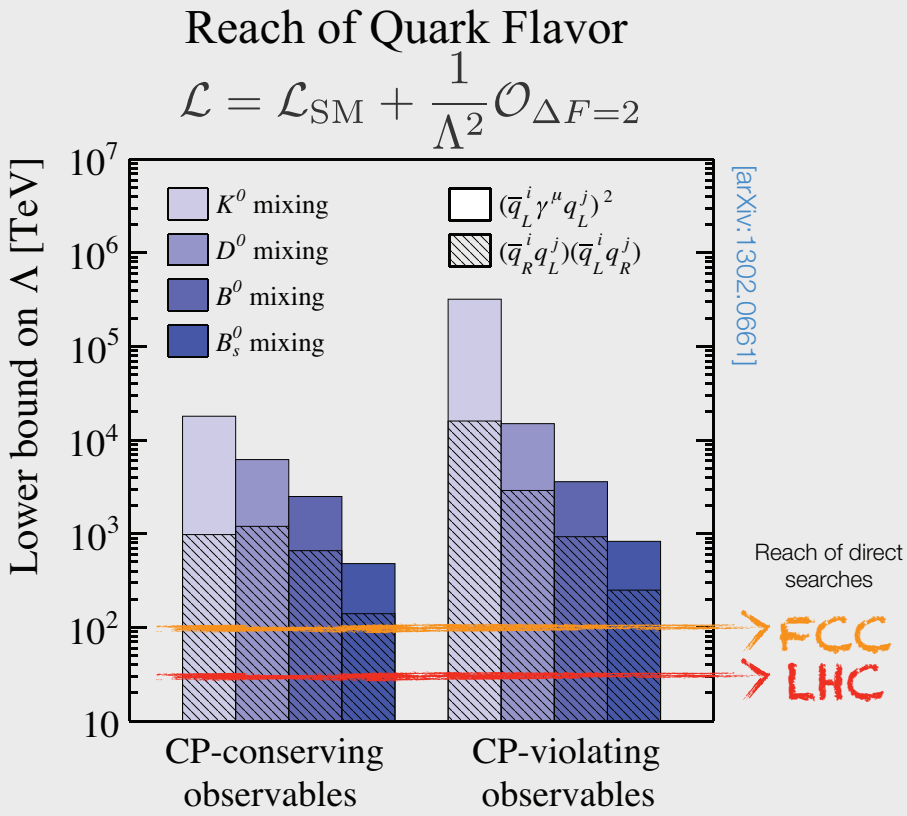
- Physics explored:
  - Rich, diverse and model-independent probe for new physics at energy scales far beyond what is directly accessible
  - promising hints of new physics from the *b*-factories and LHC are emerging from beauty decays (anomalies in $b \to sll$ and $b \to c\tau\nu$ and angular distributions)



- Status and Plans for Snowmass
  - Overleaf: https://www.overleaf.com/read/dymwtdkzgbtr
  - Tuesday 7/19 8-10 AM: Presentation and discussion of draft report
  - Thursday 7/21 8-10 AM: Cross-frontier session (with EF and TF) on flavor anomalies: Current experimental status, BSM model building, and searches for the predicted BSM mediators at the energy frontier

Weak Decays of *b* and *c*

- P5:
  - Flavor is crucial to our search for new physics in the next two decades.
  - the next 10-20 years will see the unprecedented development of a highly synergistic program of experiments, at both pp and e^+e^- colliders.



- US should aggressively pursue the potential of heavy flavor physics experiments and provide continued, stable support for the theory community

Weak Decays of Strange and Light Quarks

Evgueni Goudzovski (U. Birmingham), Emilie Passemar (Indiana)

- Physics explored:
  - Precision measurements of *K*, hyperon, π, and η/η' decays
  - CKM parameter and unitary tests; symmetry tests
  - lepton flavor/number and lepton universality tests
  - NP in *b* sector $\leftrightarrow$ K's and π's. Anomalies in one motivate searches in the other. Need a unified picture across all quark families!
    - Production and observation in π, K decays of short-lived mediators; also missing mass searches in π, K decays
  - Heavy new physics: sensitivity up to the PeV mass scale.

Weak Decays of Strange and Light Quarks

- Status and Plans for Snowmass:
  - Overleaf: https://www.overleaf.com/read/hkgrzxdnpbnn
  - Meetings: Tuesday 7/19 10 AM
- P5:
  - medium-scale initiatives, many centered in Europe and Asia; short time scales, ideal for early career physicists.
  - specifically consider an η/η' factory (REDTOP). This has been suggested since at least the last P5 and proponents deserve a clear answer

Fundamental Physics in Small Experiments

Tom Blum(U. Connecticut), Peter Winter (ANL)

- Physics explored:
  - Electric dipole moments (CP violation):
    - EDMs: discovery of new physics with energy scales up to 1000's TeV.
    - HEP opportunity: storage ring p EDMs
  - Magnetic dipole moments: theory efforts to determine hadronic terms
- Precision experiments (HEP and AMO communities: new synergies?):
  - Search for fundamental symmetry violation (C, T, P, Lorentz, CPT)
  - Tests with gravity: fundamental symmetries, GR, …
  - *This is new to Snowmass: we share the physics, can we look across funding boundaries and our personal training?*

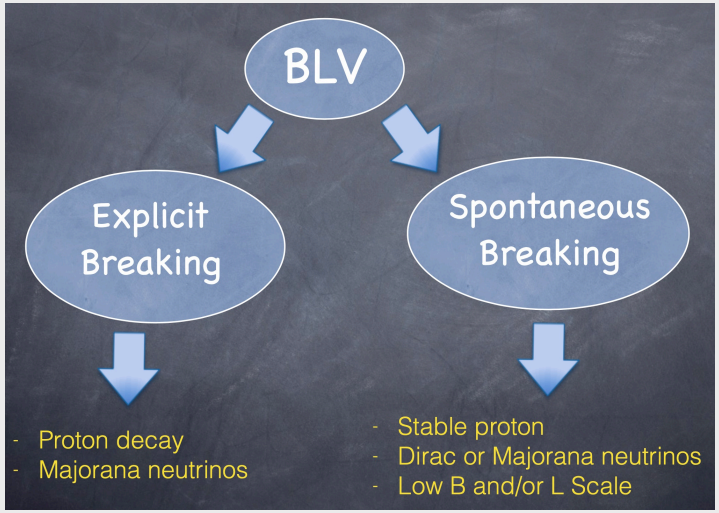
Fundamental Physics in Small Experiments

- Status and Plans for Snowmass
  - Overleaf: https://www.overleaf.com/read/ysshsctxbhck
  - Wed 07/20, 2-3:30 PM: Round Table Topic: Complementarity and synergies between HEP and AMO in EDM experiments and other precision tests
  - Fri 07/22, 8-9:30am: RF3 parallel session: storage ring and AMO EDMs, SM predictions of a_μ, symmetries and gravitational Physics
- P5:
  - Storage Ring EDMs
  - recommend crossing HEP/NP/AMO boundaries
  - and all of those need small-scale experiments in the ecosystem

B and *L* Violating Processes

Pavel Fileviez Perez (CWRU), Andrea Pocar (U Mass Amherst)

- Physics explored:
  - Baryon (*B*) and lepton (*L*) number violation is needed to explain:
    - the mechanisms for the matter-antimatter asymmetry in the Universe



- possible baryon and/or lepton number violating processes:
  - p decay, $n\bar{n}$ oscillation
  - $0\nu 2\beta$: Majorana/Dirac neutrino question
- the specific effective field theory for the Standard Model.

B and *L* Violating Processes

- Status and Plans
  - Overleaf: https://www.overleaf.com/read/mnrnsgqrdjdy
  - Much overlap with neutrino meetings:
    - $0\nu 2\beta$: Wed 7/20, 8:30 AM
    - Precision β decay: Sun 7/24, 10AM
    - Cross-Frontier with UF-RPF-NF: Wed 7/20, 4PM
- P5
  - start to break down HEP/NP divisions for $0\nu 2\beta$ and $n\bar{n}$ oscillations. Many of the same intellectual problems, methods, and people; the separation is in the way of the physics

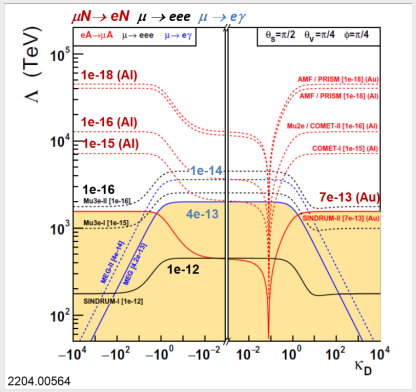
Charged Lepton Flavor Violation

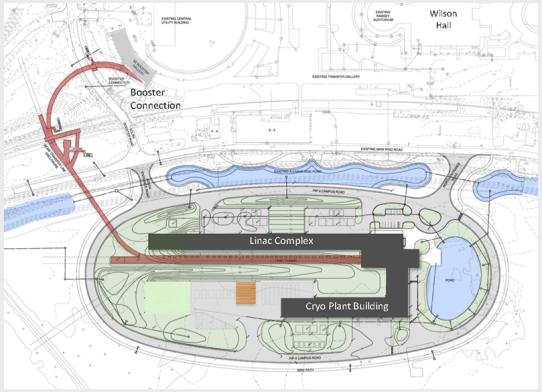
Sacha Davison (CNRS), Bertrand Echenard (Caltech)

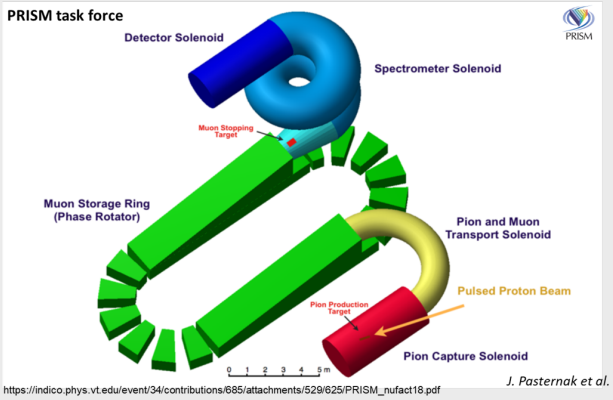
- Physics explored:
  - Charged lepton flavor violating (CLFV) processes are contact interactions that do **not** conserve lepton family numbers
  - Searches share the stage with NF and EF in studying the origin of neutrino mass, flavors and families
- Plans for Snowmass:
  - Thurs 7/21 - CLFV and heavy states: theory / experiment overview in heavy state decays (Z,H,t,Z',…) and heavy quark decays
  - Friday 7/22 - CLFV overview: theory overview, future muon experiments and next-generation facilities in the US, tau decays, muonium experiments, low energy muons
  - Sunday 7/24 - CLFV and neutrinos: theory overview, connection with g-2 and LUV, relation between neutrino NSI and CLFV

Charged Lepton Flavor Violation

- Status and Plans
  - Overleaf:https://www.overleaf.com/read/qmvzftvrhhjc
  - CLFV in muon, tau, heavy state and meson decays discussed in report
  - Emphasis on theory and future experiments (Mu2e-II, design underway) and a next generation muon facility (AMF) at FNAL to improve current sensitivity by at least two orders of magnitude, with possible DM experiment as well!
- P5:
  - The next generation of CLFV experiments and facilities are an essential component of a global program to search for NP. We hope for P5 to recommend design of a new muon-based CLFV program, with submission to next P5.



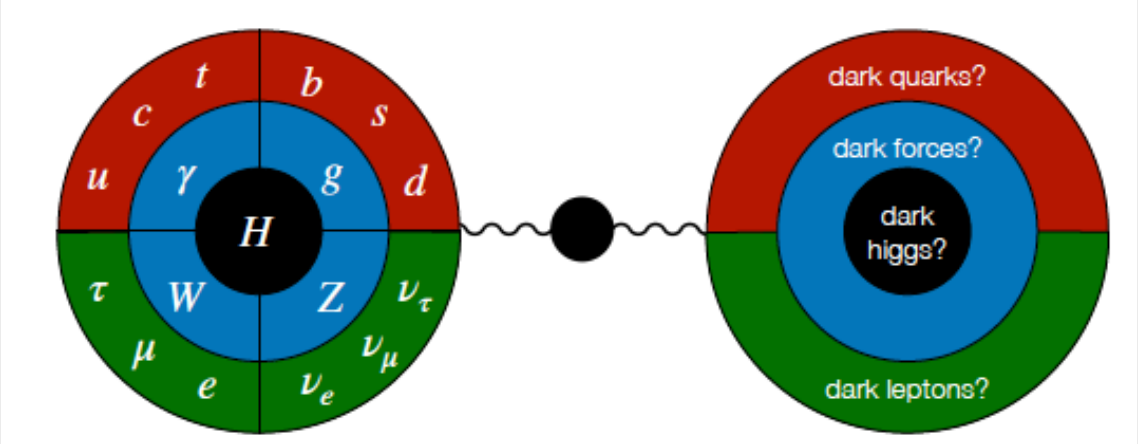




Dark Sector at High Intensity

Stefania Gori (UCSC), Mike Williams (MIT)

- Physics explored:
  - Dark sectors are a compelling possibility for new physics, motivated by DM, lightness of SM neutrinos, strong CP
  - Intensity Frontier experiments offer unique and unprecedented access
- Status and Plans at Intensity Frontier: (“big idea” white papers)
  - Dark matter production
  - Explore dark sector portals
  - Beyond minimal models
  - Experiments and Facilities
  - Overleaf: https://www.overleaf.com/read/ggdtjhvnmgjs



Dark Sector at High Intensity

- Status and Plans
    - RF6 presentation and discussion of the report: Wed 7/20 8-10am
    - RF-EF cross-frontier meeting on long-lived particles: Wed 7/20 10.30-12
    - DM (all frontiers) meeting is Tues 7/19 8am-noon
- P5: milestones in the next decade to promote US leadership
    - Exploit large multi-purpose detectors, especially Belle-II and LHCb
    - Invest in fully funding “DM New Initiative Experiments”:
        - LDMX and CCM (ν beam dump for DM)
    - Extend DMNI with focus on visible dark sector decay signals
    - Support theory efforts, especially in collaboration with experiment

Hadron Spectroscopy

Rich Lebed (Arizona State University), Tomasz Skwarnicki (Syracuse)

- Physics explored:
  - What kinds of hadrons have been/can be discovered, not just conventional $q\bar{q}$ or qqq (tetra- and pentaquarks, hybrids, etc.)?
  - What are the dominant mechanisms for their structure (molecules, diquarks, etc.), formation, and decay?
  - What is their relation to known conventional hadrons? What do they tell us about QCD matter, and how to separate it from BSM effects?
    - New states being discovered every year, now especially at LHCb, BESIII.

Hadron Spectroscopy

- Status and Plans
  - Parallel session featuring representatives from each white paper (each experiment, each major theory effort) Wed 20 July 10 AM
  - Overleaf: https://www.overleaf.com/read/bhszswwcjpnp
- P5:
  - Experiment: (1) Research group funding for spectroscopy; (2) relevant detector upgrades
  - Theory: Support for cross theory/experiment consortia, especially across high-energy/nuclear divide; multi-institution theory consortia

Summary

- Frontier-wide strong consensus:
  - physics of flavor and generations should have greater emphasis in US program, with theory support. We believe there should be a new science driver.
  - US needs to decide on a portfolio of accelerator dark sector experiments that are well-motivated, unique, and affordable
  - a new muon program at FNAL using PIP-II would enable physics in flavor, CLFV, and lepton number violation
  - our Frontier, and our discipline, needs small/medium scale experiments to be a thriving part of the US ecosystem

Emails

Working Group	Convener	Email	Convener	email
Weak Decays of *b* and *c*	Angelo Di Canto	dicanto[at]bnl.gov	Stefan Meinel	smeinel[at]arizona.edu
Weak Decays of Strange and Light Quarks	Evgueni Goudzovzski	goudzovs[at]cern.ch	Emilie Passemar	epassema[at]indiana.edu
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