Follow-up from the Rare & Precision Town Hall meeting

RF 4: Baryon and lepton number violating processes

RF 6: Dark sector studies at high intensities

RF 7: Hadron spectroscopy

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Special thanks to : A.Pocar, S. Gori, and T. Skwarnicki for provided slides!

RF4: Baryon and Lepton Number Violating Processes

Conveners: Pavel Fileviez Perez (Case Western Reserve Univ.),
Andrea Pocar (Univ. of Massachusetts-Amherst)

This Topical Group addresses the following topics:

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

- 32 LOIs received (one updated, so effectively 31 LOIs)
- 5 LOIs for which RF4 is primary TG
- 4 LOIs co-listed with another RF TG as primary
- Other LOIs co-listed with NF, TF, IF, CF, EF, UF as primaries (only nine On DBD LOIs (3 theory, 6 experiment) were co-submitted to RF4 (the others went to NF05) – produced common spreadsheet for On DBD LOI's with NF05)
- For Town Hall meeting RF04 parallel session, the following LOI's were invited
  - 7 BLV theory and phenomenology
  - 3 DeltaB=2/n-nbar experimental
  - 2 proton decay experimental
  - 9 On DBD (3 theory, 6 experimental)
  - did not invite LOI's clearly covered elsewhere (heavy flavor decays, LFV, UF, CF - 8 total) or too narrowly specific.

A.Pocar

Lepton Number Violation: Neutrinoless double beta decay experiment

- An experimental program for tonne-scale on DBD experiments is under way, with with half-life sensitivity ~10^28 years, under the stewardship of DoE-NP in the US
- Extending the experimental reach of 0nDBD is well motivated by theory and has strong complementarity with the HEP program at accelerators searching for LNV processes
- Experimental avenues to go 'beyond the tonne scale' are emerging from the community, with 6 LOI's received on 0n DBD experimental topics (1 on bolometers, 5 with ideas for Xe-136). Many more 0n DBD LOI's received by NF05. RF04 and NF05 are jointly moving ahead with a shared approach for 0n DBD. Joint workshops for 'beyond the tonne scale 0n DBD' planned in Dec. + Spring and white papers expected for:
  - CUPID-1T: distributed array of detectors, with synergies with low-mass DM, and quantum sensor development.
  - Several ambitious Xe-based detectors, which include R&D on HPGXe TPCs, the implementation of Ba daughter tagging (by NEXT and nEXO collaborators), and very large experiments (50 t with DarkNoon and ~1kton with GXe ar LXe TPCs with procurement of isotope, development of low-rad and fast electronics / scintillation detectors as key activities for the next decade)
- Snowmass can: identify the community for the future, synergies with neutrino, dark matter, QIS programs (including underground facilities), and

Baryon Number violation: proton decay and n-nbar oscillations

- Proton decay is currently heavily constrained by SuperK, but its search is well motivated
- The search of proton decay mostly benefits from increased detector size. HyperK will naturally take over from SuperK
- Two LOI's received, from SuperK and HyperK: both experiments have a rich neutrino program (solar, accelerator, supernova). DUNE and JUNO presented at the BLV workshop in July, but did not submit proton-decay LOI's.

- DeltaB = 2 searches are well motivated, and experimentally searched in n—nbar oscillations
- Four LOIs received (three invited, one very technically specific), all stemming from a topical workshop in the Summer and thus well-coordinated.
- The long-term program looks at the European Spallation source with HIBEAM/NNBAR sequence, with important development work at ORNL.
- On the shorter time scale, DUNE can reach interesting sensitivity.
- Contributed papers are expected for all phases of the program, as outlined in the LOIs

BN and LN violation: theory and phenomenology

BLV theory (cosmology and colliders):

- "The Baryon Asymmetry of the Universe - Mechanisms at the Low Scale", G. Elor et al.
- "Neutrino Minimal Standard Model — a unified theory of microscopic and cosmic scales", M. Drewes et al.
- "Discovery and Exclusion Potential of Future Colliders for Supersymmetry Signatures", E. Thomson et al.
- "Opportunities and signatures of non-minimal Heavy Neutral Leptons", Matheus Hostert et al.
- "BSM Physics at the Electron Ion Collider: Searching for Heavy Neutral Leptons", K. Xie et al.

On DBD theory (EFT's and LQCD):

- " Neutrinoless double beta decay - effective theory and simplified models", W. Dekens et al.
- "Bridging particle and nuclear physics for neutrinoless double beta decays with EFTs", E. Mereghetti et al.
- "Nuclear matrix elements for BSM searches from Lattice QCD", W. Delmold et al.

RF6: Dark Sector Studies at High Intensities

Conveners: Stefania Gori (UCSC),
Mike Williams (MIT)

This Topical Group addresses the following topics:

- Theory of dark sectors (Brian Batell, Philip Schuster)
- Dark sectors at electron-positron colliders (Chris Hearty)
- Dark sectors at fixed target / beam dump experiments (electron, positron, proton, and muon beams) (Gordan Krnjaic, Phil Harris, Natalia Toro)
- Dark sectors at kaon factories (Babette Dobrich, Jure Zupan)
- Low-mass dark sectors at energy-frontier facilities (cross-group with EF09 - BSM: More general explorations / EF10 - BSM: Dark Matter at colliders) (Phil Ilten)
- Dark sectors at neutrino experiments (cross-group with NF03 - Neutrino physics - BSM) (Pilar Coloma)
- Other experimental opportunities

54 LOIs received in total.
23 LOIs with RF6 as primary topical group. 19 talks at the RF town-hall
The other 31 LOIs are cross group with: 3-AF, 2-CF, 12-EF, 12-NF, 2-other RF

Our working group contains 7 main topics (and corresponding sub-conveners):

1. Theory (B. Batell (U. of Pittsburgh, P. Schuster (SLAC))
2. e^+e^- experiments (C. Hearty (UBC))
3. Fixed-target experiments (G. Krnjaic (Fermilab), P. Harris (MIT), N. Toro (SLAC))
4. Kaon factories (B. Dobrich (CERN), J. Zupan (U. of Cincinnati))
5. Low masses @ EF facilities (P. Ilten (U. of Cincinnati))
6. Neutrino experiments (P. Coloma (IFT))
7. Other opportunities

Several LOIs submitted for each topics.

S. Gori

Main topics and highlights (1)

Dark sectors at high and middle energy colliders (3 talks):
Dark sectors at LHCb.
(Long lived & prompt) dark sectors at Belle II.

Dark sectors at kaon factories (3 talks):
NA62 (both Kaon decays and beam-dump mode), KOTO, and KLEVER (future exp.).
Theory effort in interpreting results in terms of several benchmark models.

Dark sectors at eta factories (1 talk)
Jefferson Eta Factory & REDTOP (future exp.).
Collaboration of theorists (model landscape and predictions) and experimentalists.

Dark sectors at MEGII (1 talk)
Searches for lepton flavor violating dark sectors @ the proposed upgrade MEGII-fwd

Dark sectors at Neutron Facilities (1 talk)
Search for neutron transformations into sterile neutrons @
Oak Ridge National Laboratory + European Spallation Source

Main topics and highlights (2)

Theory focused (2 talks):
massless dark photon
milli-charged particles

Complementarity
of the several accelerator probes

Dark sectors at fixed target experiments (8 talks):

Complementarity of invisible and (semi)visible searches

Proton beam dump experiments:

- 1 & 10 GeV Fermilab proton beams. Collaboration with accelerator frontier.
- 120 GeV Fermilab proton beam: DarkQuest experiment.

Lepton beam fixed target experiments:

- HPS experiment. Electron beam dump.
- CBETA low energy electron beam.
- e^- (BDX exp.) beam dump & e^+ (thin & thick) fixed target experiments at JLAB. Searches for light Dark Matter.
- LDMX experiment (e^- beam) & M3 (μ^- beam). Missing momentum.

Photon beam fixed target experiments:

GlueX, LEPS, LEPS2, FOREST, A2/MAMI, NPS/CPS, PRIMEX II.

RF7: Hadron Spectroscopy

Conveners: Tomasz Skwarnicki (Syracuse),
Richard Lebed (ASU)

This Topical Group addresses the following topics:

- Heavy-Quark Conventional Hadrons (Bryan Fulsom, Alexis Pompili, Elena Santopinto)
- Heavy-Quark Exotic Hadrons (Liupan An,Ryan Mitchell, Sasa Prelovsek)
- Light-Quark Exotic Hadrons (Sean Dobbs, Justin Stevens, Adam Szczepaniak)

Hadron Spectroscopy Summary of LoIs

- 5 LoIs from ongoing experimental programs (LHCb, BelleII, CMS, BESIII, GlueX): seeking support for continued participation from U.S. and upgrade programs
- 6 LoIs related to future new facilities:
  - Three future e^+e^- tau-charm factory proposals (USTC, Novosibirsk, repurposing of BEPC as dedicated J/ψ factory?): seeking American participation [combined whitepaper]
  - Potential of Z-pole e^+e^- machines: capability studies (nothing yet on hadron spectroscopy)
  - EIC: seeking support for EIC and collaborators for development of hadron spectroscopy program
  - Dedicated charm-photoproduction facility: EIC is not optimal, JLab upgrade?
- 5 theory related LoIs:
  - JPAC: theorists & experimentalists collaborating on amplitude analysis tools: need support
  - Lattice QCD (2 LoIs): support for simulations of more complicated hadrons
  - Development of phenomenological models of diquark-based and hadronic molecules (2 LoIs): support for theorists, seeking more interactions with experimentalists

T. Skwarnicki

Introduction

- A lot of fundamental questions in hadron spectroscopy have no satisfactory answers yet:
  - Do multiquark hadrons made out of diquarks exist (diquark baryons, compact tetra- and penta-quarks etc.)?
  - Do mesons bind with mesons or baryons to create hadronic "molecules"?
  - Can gluons act as valence constituents, i.e., do glueballs and hybrids exist?
- Lattice QCD modelling of more complicated hadronic structures, especially of unstable ones, is still in infancy. The experimental measurements, and theoretical modelling to explain the results, are key to providing the answers.
- A lot of discoveries in recent years have been driving a renaissance of hadron spectroscopy as an important topic in particle physics. They produced most cited papers for the heavy-flavor experiments. Nuclear community has dedicated experiments to light hadron spectroscopy.
- RF7 Hadron Spectroscopy group focuses on heavy exotic and conventional hadrons and light hadron exotics
- There is a large number of experimental and theoretical physicists working on hadron spectroscopy, crossing the boundaries between the high-energy and nuclear communities. Each of three RF7 meetings in September attracted 60-70 participants (94 subscriptions to RF7 mailing list)

Hadron Spectroscopy LoIs

Experimental facilities producing b&c hadrons

- LHCb:
  - At present the LHC is the most luminous heavy-flavor (b,c) factory. The LHCb detector has unique capabilities (high bandwidth triggers on low p_T muons and final-state hadrons with a detached vertex, π/K/p discrimination). LHCb upgrade I in progress (50 fb^{-1}).
  - Run 1+2 (9 fb^{-1}) led to the most unexpected discoveries from the LHC: pentaquarks in $J/\psi p$, tetraquarks in $J/\psi\phi$, $J/\psi J/\psi$, D^+K^-, narrow baryon families of Ω_c^*,Ω_b^*. Light-hadron exotics via Central Exclusive Production. Ongoing and future upgrades to increase luminosity.
  - Seeks continued support for American participation in Runs 3-5, including R&D/detector funds for Upgrade II (~2030 300 fb^{-1})
- CMS (& ATLAS):
  - Operate at higher luminosities than LHCb (up to HL LHC 4000 fb^{-1}). Triggering for heavy flavors is a challenge. No hadron ID. Wide acceptance muons detector. "Parking" b-quark data. Made contributions to conventional- and exotic-hadron spectroscopies.
  - At unique position to confirm the LHCb discoveries in hadron spectroscopy or make their own (tetraquarks in Upsilon-Upsilon?)
  - Continuation of the strong U.S. support to the Phase-I and Phase-II LHC upgrade program. Triggering and capability study for hadron spectroscopy. Raise profile of hadron spectroscopy within the collaboration.
- BelleII:
  - New e^+e^- B-factory on the way to collect by 2031 50x larger data sample than in Belle & BaBar. R&D project for ultra-high luminosity (~2032 5x). Smaller rates than at hadron colliders but cleaner environment. Easy triggering, good photon detection and large absolute tracking efficiencies, full event reconstruction possible.
  - Many unexpected discoveries at the previous B-factories: X(3872),Y(4260),$Z_c(4430)^+$,Z_b^+ states,... Precision bottomonium spectroscopy below and above open-flavor threshold. ISR to scan charm threshold. $\gamma\gamma$–collisions production of hadrons.
  - Seeks continued support for American participation, including for detector and machine upgrades necessary to reach luminosity goals
- Future e^+e^- machines operating at Z-pole:
  - Since 10 GeV B-factories have no access to b-baryons, which are very interesting on their own and a gateway to charm-baryon exotics, e.g., $\Lambda_b \to K^-(P_c^+ \to J/\psi p)$, Z-pole experiments provide a way forward. Easier environment than LHC for detection of neutrals.
  - Flavor-physics proposals at Z-pole. Capabilities in hadron spectroscopy to be explored.

Hadron Spectroscopy LoIs
Experimental facilities at charm threshold

- BESIII:
  - The latest generation of e^+e^- tau & charm factory 2-4.9 GeV. Unique access to hidden-charm exotic hadrons via precision scanning above the open-charm threshold, and to light hadron exotics (glueballs & hybrids) via extended runs at J/ψ, multiquark states with s-quarks via low-energy scans. Precision charmonium spectroscopy via runs at $\psi(2S)$.
    Many discoveries in the past: $Z_c(3900)^+$, $Z_c(4020)+$, $Y(4220)$&$Y(4320)$, $X(1835)$..
  - 5-10 year program. Energy and luminosity (3x) upgrades of BEPCII collider under consideration.
  - Seeking support for renewed American participation
- Future e^+e^- tau & charm factories:
  - 50x luminosity of BESIII. Higher energy range (up to 7 GeV).
    Proposals from China (USTC) and Russia (Novosibirsk).
  - In addition, monochromatic beams (at BEPC?) as dedicated J/ψ factory.
  - Limited US participation so far. Seeking broader involvement of US community.

Hadron Spectroscopy LoIs
Other facilities

- GlueX at Jlab (electron → photon beam at fixed target):
  - Unique capabilities. On the quest to discover light-quark hybrid states. Best sensitivity so far for photoproduction of charmonium via s-channel (e.g., limits on photoproduction of P_c^+ states).
  - Ongoing experiment. Results will shape future running scenarios.
  - Support for future running and detector upgrades needed.
- Electron-Ion Collider:
  - A major new facility to be located at BNL (~2031). Higher collision energy opens up t-channel production of hidden-charm exotic (and conventional) hadrons. Observation of exotics, or lack of, will provide unique input into their nature. Dependence on A for various eA collisions.
  - Initial studies have been performed.
  - Seeking support for EIC and collaborators for development of hadron spectroscopy program
- Charm-photoproduction factory:
  - EIC will not be optimal for charm photoproduction. Dedicated facility with a lower-energy beam, higher luminosity and polarized beams would allowed for more insightful studies of production for XYZP states.
  - Jlab upgrade?

Hadron Spectroscopy LoIs Theory

- Need for amplitude analysis
  - Naïve mass peak fits often lead to naïve results. Amplitude analysis of data is often necessary, which come with complex theoretical and practical aspects, especially for initial- and final-state particles with spin, multi-body complications. Employs strong theorems on analyticity in QFT. Minimizes model dependence.
  - Theorists from the JPAC group have successfully collaborated with lower- and higher-energy experiments (COMPASS, CLAS, GlueX, BESIII, BaBar, LHCb), to enable proper amplitude analyses. In addition, development of generic formalisms and software tools.
  - Need of support for this type of collaboration of theorists and experimentalists for the ongoing and future experiments
- Lattice QCD:
  - Two LoIs: a generic one from USQCD, and a dedicated one from American and European groups simulating hadrons
  - The latter focuses on challenges in simulation of exotic hadrons. Unique challenges for multiquark states, multiple coupled channels.
  - Identify experimentally accessibly states, which can also be reliably simulated. Support for simulations relevant to hadron spectroscopy is needed, not only computing but also personnel.
- Diquark structures in hadron spectroscopy:
  - Recent experimental results provide more promising evidence for diquarks than before. This LoI was submitted by many theorists interested in diquark models, together with experimentalists from a wide range of experiments.
  - White paper will identify theoretical and experimental inroads to advance understanding of the role of diquarks in hadron building
  - US support for theoretical work in this direction is needed
- Hadron-hadron spectroscopy
  - Many puzzling narrow states discovered recently are near meson-meson and meson-baryon thresholds, suggesting "molecular" bound or virtual states.
  - Similar LoI to the one above, but using a different approach to hot subject in hadron spectroscopy. Both mechanisms present?


The Evening
EXTRA!

Goal for the R&P Town Hall meeting

- This meeting was held in response to Letters of Interest (LOIs) submitted to our Frontier. Each presentation at the meeting should address the following points:
  - What is the physics/motivation for each LOI?
  - What will you work on between now and Snowmass, and what is your schedule for developing a contributed paper?
  - What common data sets, joint efforts, etc. do you need?
  - What would you like to come out of the Snowmass process?
- See CPM website: https://indico.fnal.gov/event/45713/

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 will help conveners to prepare the Snowmass Planning Meeting that will take place on October 5 - 8, 2020 at Fermilab (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 – July 31, 2021)

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/

Final Product: Snowmass 2021 Report

The Town Hall meeting is 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.