

## RF4: Baryon and Lepton Number Violating Processes

Pavel Fileviez Perez (Case Western Reserve University)  
Andrea Pocar (University of Massachusetts, Amherst)



<https://snowmass21.org/rare/blv>

# RF4: Baryon and Lepton Number Violating Processes

co-Conveners: Pavel Fileviez Perez (Case Western Reserve Univ.) and Andrea Pocar (UMass, Amherst)

## Main Physics Topics:

- *Theories for baryon and lepton number violation* — P. Fileviez Perez (CWRU), M.B. Wise (Caltech)
- *Neutrinoless double beta decays* — V. Cirigliano (INT), A. Pocar (UMass)
- *Baryon and Lepton number violation at colliders* — R. Ruiz (Cracow, INP), E. Thomson (UPenn)
- *Proton decay* — E. Kearns (Boston Univ.), S. Raby (Ohio State Univ)
- *$n$ - $\bar{n}$  oscillations* — K. Babu (OSU), L. Broussard (ORNL)
- *Exotic  $L$  and  $B$  violating processes* — S. Gardner (Univ. of Kentucky), J. Heeck (Virginia)
- *Connections to Cosmology (Baryogenesis Mechanisms)* — A. Long (Rice Univ.), C. Wagner (Univ. of Chicago/ANL)

**Drivers:** *Explore the unknown, The origin of  $B$  and  $L$  violation is crucial to understand the nature of neutrinos and the mechanism to explain the matter-antimatter in the Universe. An unique window for physics beyond the SM.*

**P5:** *Strong support for these physics topics*

**Plans:** *Finishing the RF4 Report*

**Overlap:** Overlap with the neutrino frontier (proton decay, neutrinoless double beta decay) and Cosmic Frontier (Baryogenesis)

# the RPF04 activities (<https://snowmass21.org/rare/blv>)

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Kickoff meeting:

BLV circa 2020 (July 6-8, 2020 — hosted by CWRU)

<https://artsci.case.edu/blv2020/>

All topical leaders, and others, presented for an excellent overview (theory, experiment, and their interplay)

All slides are posted on indico: [day1](#), [day 2](#), [day 3](#)



ACFI Workshop

Aug 3-6, 2020, Univ. of Massachusetts-Amherst

<https://indico.fnal.gov/event/44472/timetable/#20200803>

Co-organizers:

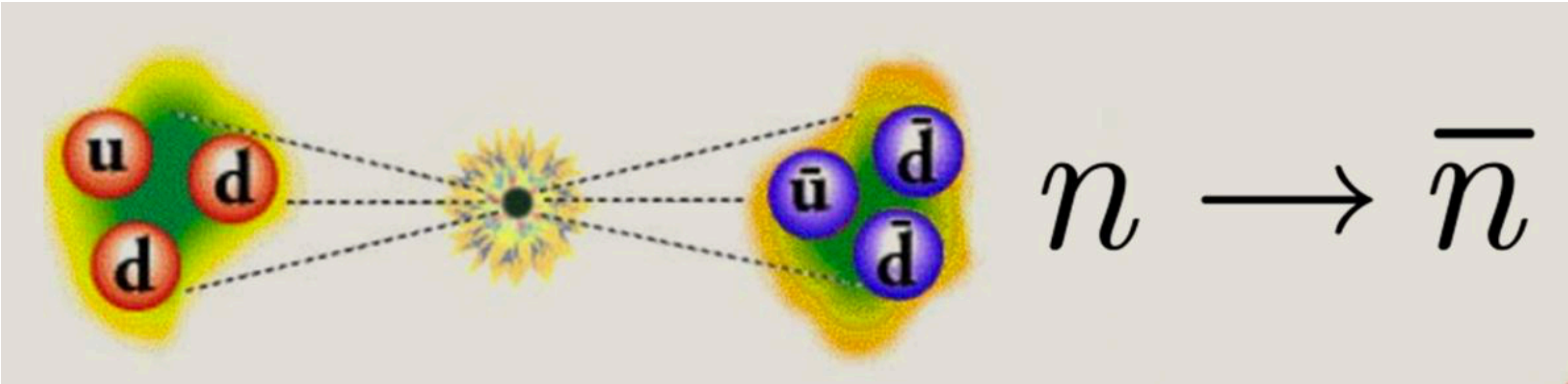
Joshua Barrow (University of Tennessee)

Leah Broussard (Oak Ridge National Laboratory)

Jordy de Vries (University of Massachusetts Amherst/Riken Brookhaven)

Michael Wagman (Fermi National Accelerator Laboratory)

Theoretical Innovations for Future Experiments  
Regarding Baryon Number Violation by Two Units  
I



# Neutrinoless double beta decay — activities with the Neutrino Frontier

The Neutrino Frontier (NF05) has organized four mini-workshops, two theoretical and two experimental, in July and August. Large community, HEP/NP overlap, many frontier want to be there (latest one if CF)

August 2020

- 19 Aug Mini Workshop: Onubb Experiment II
- 12 Aug Mini Workshop: Neutrino Electromagnetic Properties
- 05 Aug Mini Workshop: Onubb Experiment I

ideas for the future,  
moderated by Wick Haxton

status of the field

July 2020

<https://indico.fnal.gov/category/1172/>

- 22 Jul Mini Workshop: Nuclear theory of neutrinoless double-beta decay
- 15 Jul Mini Workshop: Particle theory of neutrinoless double-beta decay

Experiment

Theory

Slides presented by Andrea in conclusion to yesterday's mini-workshop illustrating the new “benchmarks” for  $0\nu$  DBD (experimental goals, theory input) (developed with Vincenzo Cirigliano and Michael Ramsey-Musolf)



# Neutrino theory workshop (Pavel F. P.)

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September 21 to 23 (MTW)

10:00-14:00 US Central Time. (8:00 to 12:00 Pacific, 17:00 to 21:00 in Europe)

Six 2-hour sessions - two-per-day - broad topics

- 1 - Neutrinos in astrophysics and cosmology
- 2 - Neutrino interactions with matter
- 3 - Neutrinoless double-beta decay and other nuclear-physics probes of neutrino properties
- 4 - Neutrino phenomenology (including oscillations, collider searches, charged-lepton and meson processes)
- 5 - Not-neutrino phenomenology of neutrino experiments (e.g. dark sector searches)
- 6 - Neutrino mass and flavor model-building

- Each session: 1-2 plenary talks (~20 minutes each). Plenary speakers asked to aim their talks towards the future: define outstanding questions and discuss how these will be attacked in the coming years. Plenary talks should also aim to establish connections among different sub-topics, different topical groups in TF and NF, and other areas of Science.
- The rest of the session will consist of discussions and contributed talks (~10 minutes each): contributed talks providing a talk title, abstract, and the best-fit session. Contributed talks are an excellent opportunity for younger people to contribute (connection to specific LOIs)

## RPF Town Hall Meeting (October 2)

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- 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 – worked together)

# RPF Town Hall Meeting (October 2)

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- 22 invitations to present LOIs sent out
- Summary of invited LOIs summarized in Gdoc at: [https://docs.google.com/spreadsheets/d/13Wd7\\_npWUHV0dwUB4nANzG2LfqyUdZgT7tPff9qRLqc/edit#gid=193313944](https://docs.google.com/spreadsheets/d/13Wd7_npWUHV0dwUB4nANzG2LfqyUdZgT7tPff9qRLqc/edit#gid=193313944)

## Invited LOI breakdown

- 7 BLV theory and phenomenology
- 3  $\Delta B=2/n-nbar$  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)



# Snowmass Community Planning Meeting (CPM, October 5-8)

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session #110 – “Baryon and Lepton Number Violating processes”

- organizers: Pavel Fileviez Perez, Andrea Pocar, Lisa Koerner, Danielle Speller, Patrick Decowski
- speakers (1 theory, 3 experimental):
  - Kaladi Babu (BLV theory)
  - Julieta Gruszko (UNC) – On DBD experiment
  - Leah Broussard (ORNL) –  $n$ - $\bar{n}$  experiment
  - Ed Kearns (BU) – proton decay
  - discussion (15-20 minutes)

# Snowmass Community Planning Meeting (CPM, October 5-8)

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session #51 —

“Requirements for low background and underground detectors” (synergy between DM and DBD, instrumentation)

- organizers: Mayly Sanchez, Ben Jones, Hugh Lippincott, Andrea Pocar
- talking to session #115 organizers: Gabriel Orebi-Gann, Danielle Speller, Patrick Decowski, John Orrell
- two speakers (we think):
  - Josh Klein (Penn, tbc) — Strategy (i.e. what does this community want out of snowmass, what are the issues that we need to address, NP/HEP borders, beyond BRN, reach goals, etc)
  - Roxanne Guenette (Harvard) — Instrumentation in view of BRN/CPAD
  - then discussion

# Neutrinoless Double Beta Decay: Beyond the "Tonne-Scale" – I

**Date:** Wednesday, December 9, 2020 - 12:00pm to Friday, December 11, 2020 - 4:00pm

**Location:** online

- ACFI/Snowmass, December 9-11 (virtual) — co-organized by RF04 and NF05
- organizers: Julieta Gruszko, Lisa Kaufman, Ben Jones, Jordy de Vries, Andrea Pocar
- <https://indico.fnal.gov/event/46424/timetable/#20201209>
- 5 panels, only a few invited talks, working session to define white papers



## II. THEORIES FOR BARYON AND LEPTON NUMBER VIOLATION

Pavel Fileviez Pérez (CWRU), Mark B. Wise (Caltech)

## III. NEUTRINOLESS DOUBLE BETA DECAY

Vincenzo Cirigliano (INT), Andrea Pocar (UMass)

## IV. BARYON AND LEPTON NUMBER VIOLATION AT COLLIDERS

Richard Ruiz (Cracow, INP), Evelyn Thomson (UPenn)

## V. PROTON DECAY

Ed Kearns (Boston Univ.), Stuart Raby (Ohio State Univ.)

## VI. N-NBAR OSCILLATIONS

Kaladi Babu (OSU), Leah Broussard (ORNL)

## VII. MORE EXOTIC L AND B VIOLATING PROCESSES

Susan Gardner (Univ. of Kentucky), Julian Heeck (Univ. of Virginia)

## VIII. CONNECTIONS TO COSMOLOGY

Andrew J. Long (Rice Univ.), Carlos Wagner (Univ. of Chicago/ANL)

## NOTE on neutrinoless double beta ( $0\nu\beta\beta$ ) decay reports:

- The ACFI-Snowmass workshop on the medium/long-term future of DBD defined the RF04/NF05 collaboration on this topic
- Our RF04 report has a limited length section on DBD
- The NF05 report has a much more detailed section on DBD collecting what emerged during the Snowmass 21 process (LOIs, White Papers, workshops)
- Our two reports have been written with complementarity on mind



# Program for this meeting

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Tuesday 11:00 - 12:30

- LNV Theory (Vincenzo Cirigliano)
- LNV at colliders and BLV processes (Bhupal Dev)

Tuesday 14:00 - 15:30

- BNV Theory (Clara Murgui)
- Experimental searches for  $n$ - $n$ bar (Leah Broussard)

Wednesday 11:00 - 12:30

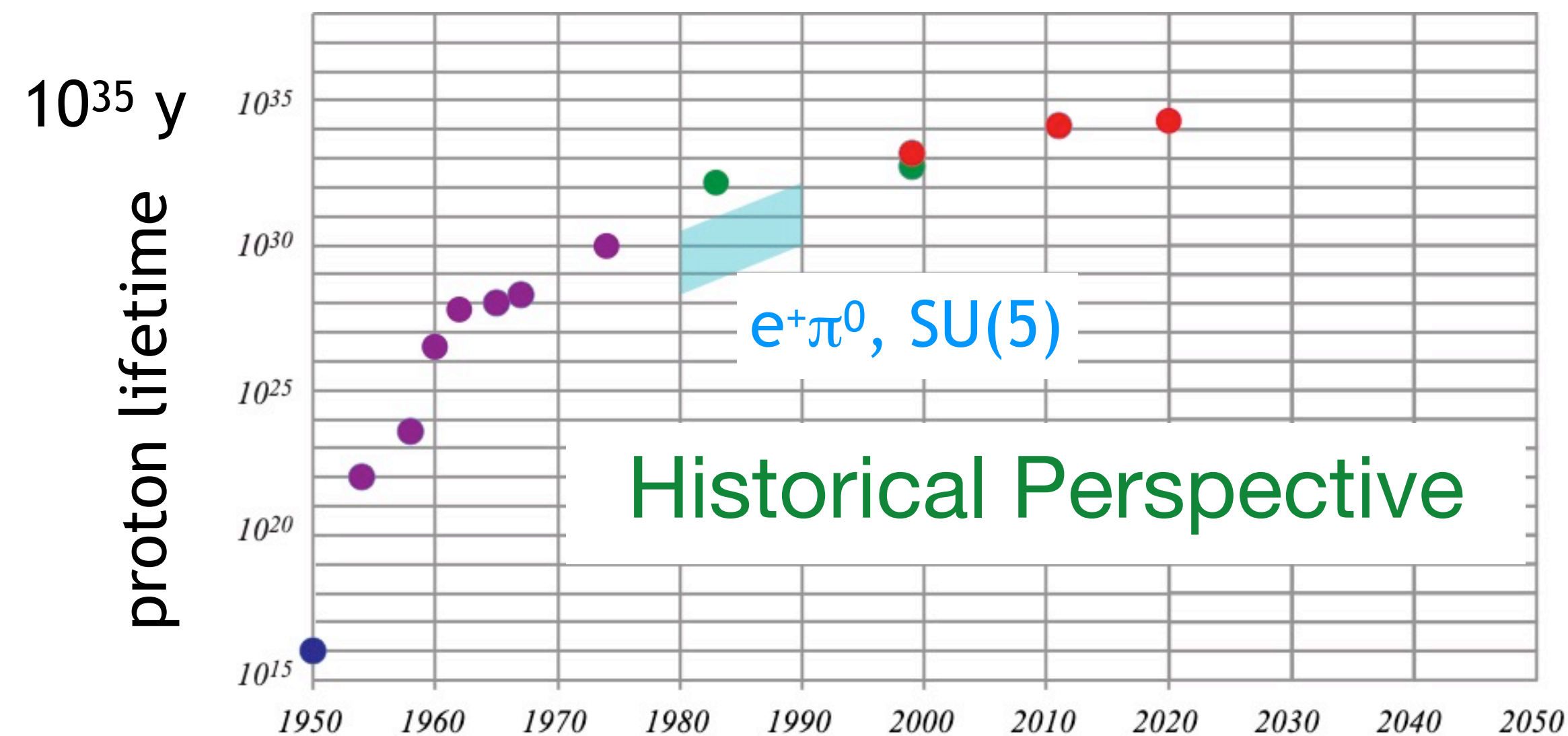
- BNV with neutrino experiments (Juan Pedro Ochoa-Ricoux)
- Baryogenesis and BLV (Gilly Elor)

# Experimental program: proton decay

- Best sensitivity currently held by SuperK (450 kt yr and 260 kt yr):

$$p \rightarrow e^+ \pi^0 \quad 2.4 \times 10^{34} \text{ y (90\% CL)}$$

$$p \rightarrow \nu K^+ \quad 5.9 \times 10^{33} \text{ years}$$



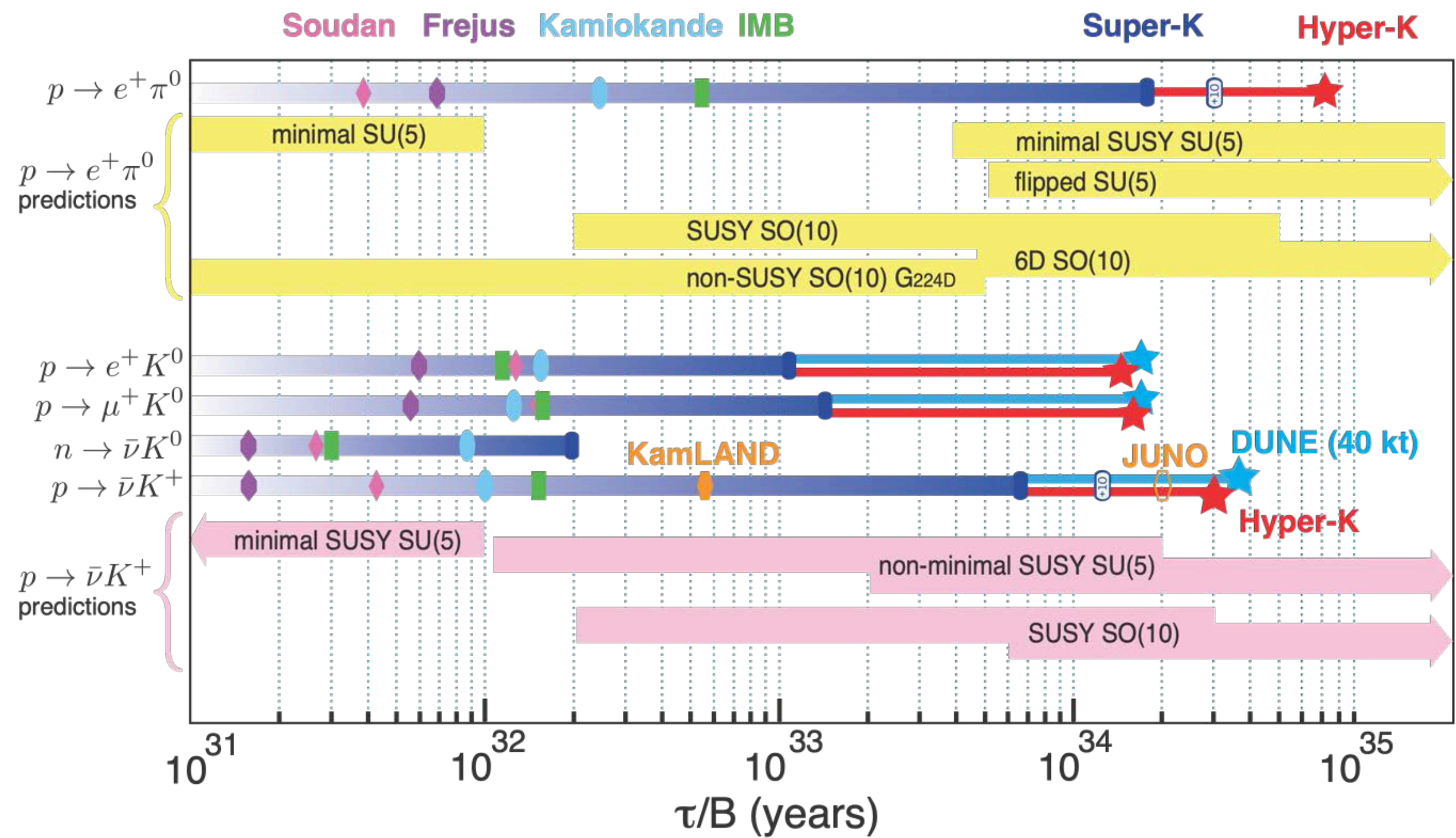
Requires very large detectors:

- Water Cherenkov → HyperK
- Liquid scintillator → JUNO
- LAr → DUNE
- WbLS → THEIA?



# Proton decay foreseeable sensitivity

(from Ed Kearns)



current and next generation experiments are looking in theoretically motivated regions, even if they can't cover whole regions

—> see talk by j. Pedro Ochoa-Ricoux

# Neutron-antineutron oscillation

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- $\Delta B = 2$  searches are well motivated, and experimentally searched in  $n$ – $\bar{n}$  oscillations
- R&D path to  $n$ - $\bar{n}$  search program underway by worldwide collaboration
- Staged approach:
  - Early stage at Oak Ridge
  - Mid/long stage at ESS (up to 50m beam line) with HIBEAM/NNBAR sequence
- Complementarity between intranuclear & free searches
- Especially important in case a signal is detected
- DUNE, e.g., will search for intranuclear  $n$ - $\bar{n}$

—> see Leah Broussard's talk



# BLV @ colliders

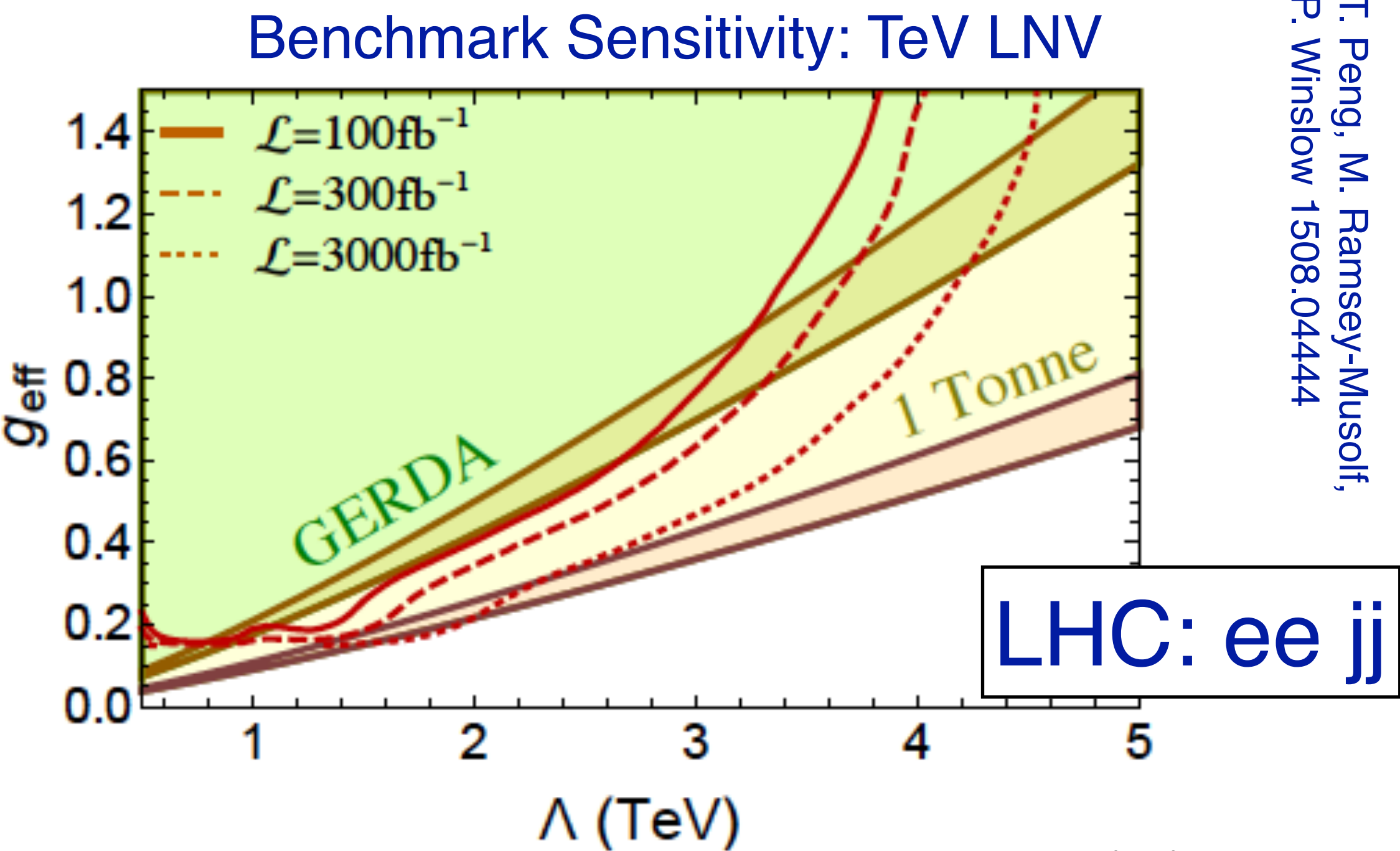
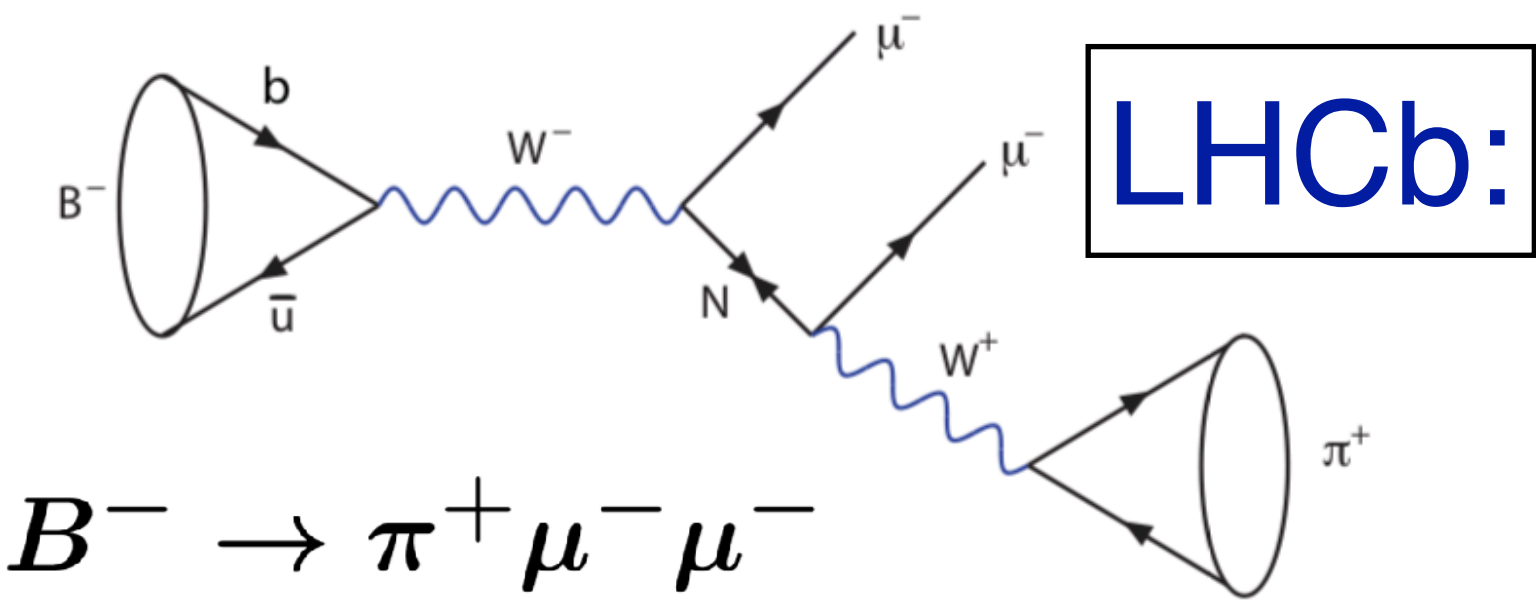
High energy colliders offer ample opportunity to test BLV processes

- R-parity violation in SUSY
- Majorana particles

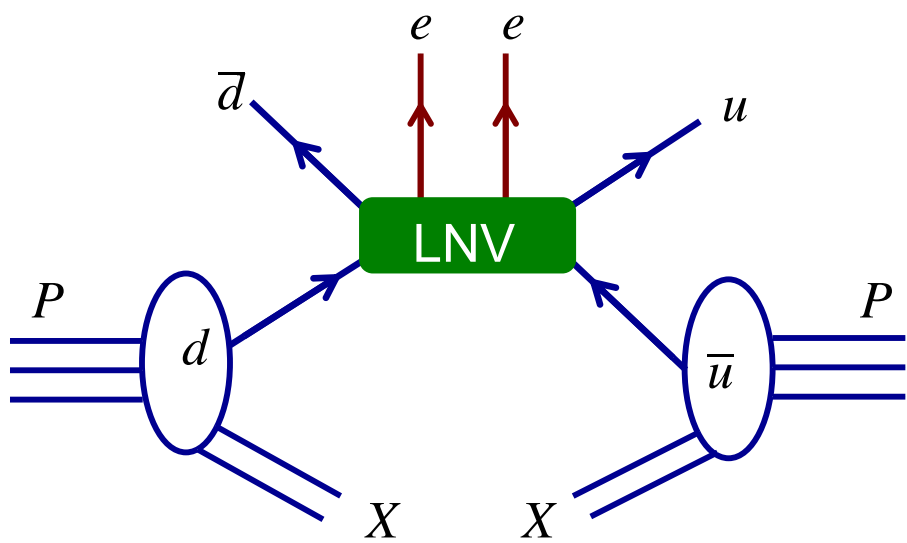
Required tools (generally):

- particle ID
- jet reconstruction
- displaced vertices
- missing energy

→ see Bhupal  
Dev's talk



T. Peng, M. Ramsey-Musolf,  
P. Winslow 1508.04444





# LN $\nu$ : $0\nu\beta\beta$ decay experiment

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- An experimental program for tonne-scale on DBD experiments is under way, with half-life sensitivity  $\sim 10^{28}$  years, under the stewardship of DoE-NP in the US
- Extending the experimental reach of OnDBD is well motivated by theory and has strong complementarity with the HEP program at accelerators searching for LN $\nu$  processes
- Experimental avenues to go ‘beyond the tonne scale’ are emerging from the community.
- Some ideas are out, among others, for very large tellurium and xenon detectors
- Challenges include: isotope procurement, solar neutrino backgrounds, light collection efficiency, read-out electronics, etc.
- $\rightarrow$  more detail in the NF05 report