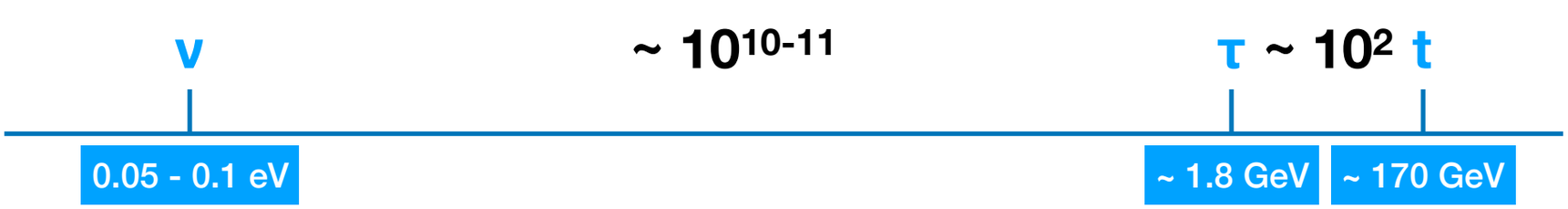
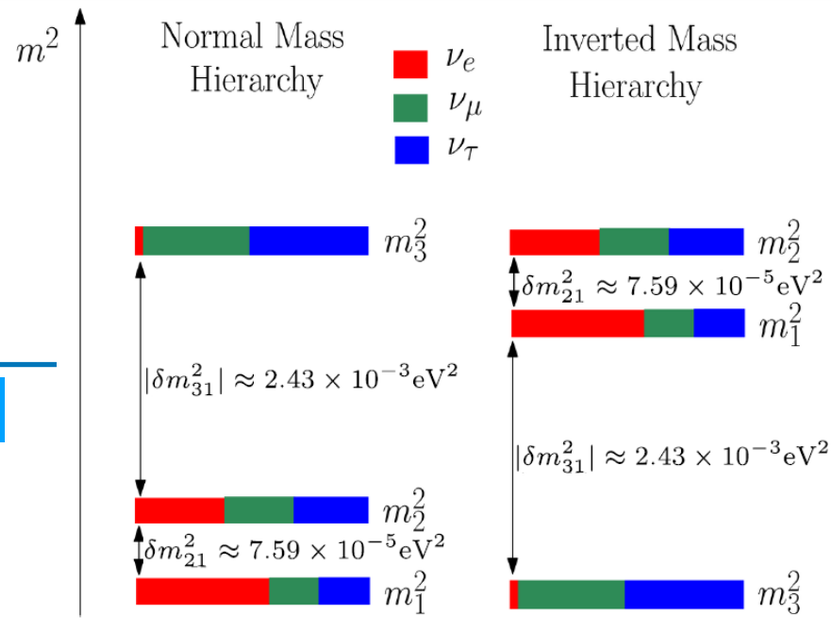
Most Clear Evidence for the Physics beyond the Standard Model

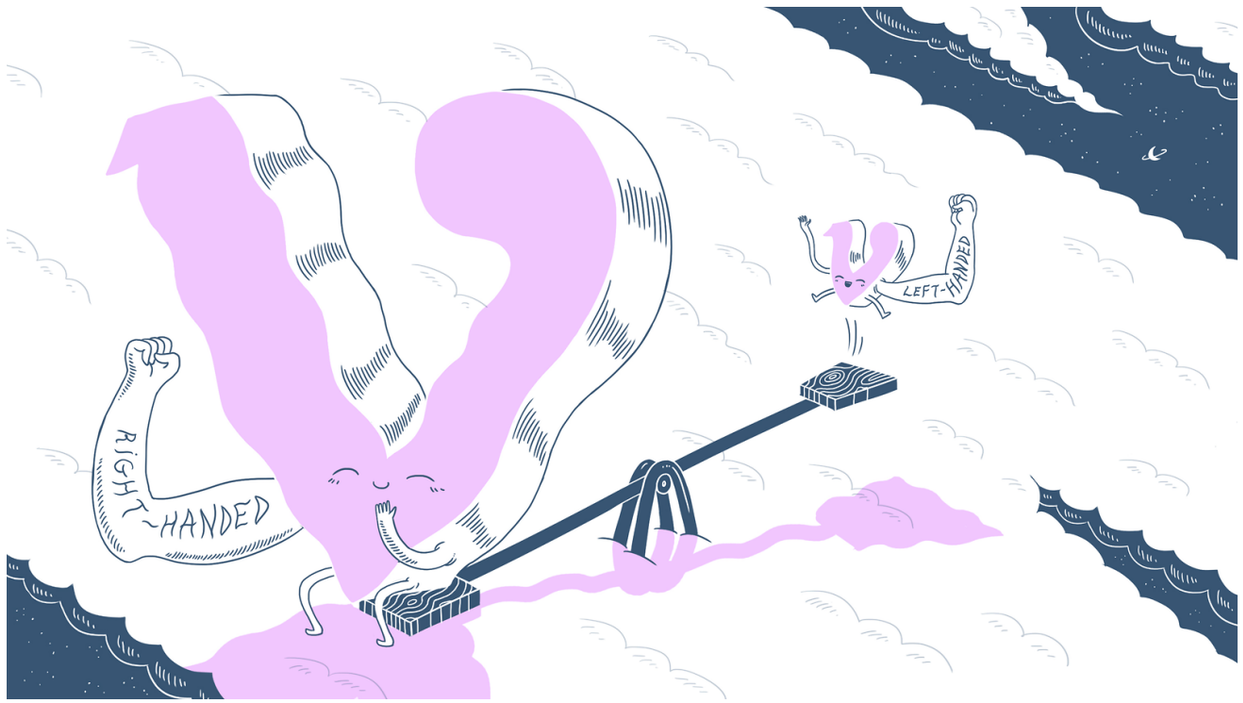
- Discovery of neutrino oscillations
  - At least two mass eigenvalues are non-zero
  - Distances between the heaviest neutrino, charged lepton, and quark





  - What is the mechanism for masses of neutrinos
    - Is it Dirac mass model like other charged fermions?
    - Where are right-handed neutrinos than?

- See-saw Model
  - Right-handed neutrinos with heavy masses so that could not be detected by experiments at low energies
  - Neutrinos are Majorana type
    - Gives off-diagonal components for mass matrix
    - Two solutions with huge order difference
- $M_\nu \sim \frac{\lambda^2 y_\nu^2}{M_N} \ll M_N$
    - where, λy_ν denotes Dirac mass of neutrino and M_N means Majorana mass
    - As mass of heavy neutrino grows, the Standard Model neutrino's mass becomes smaller
      - Like see-saw



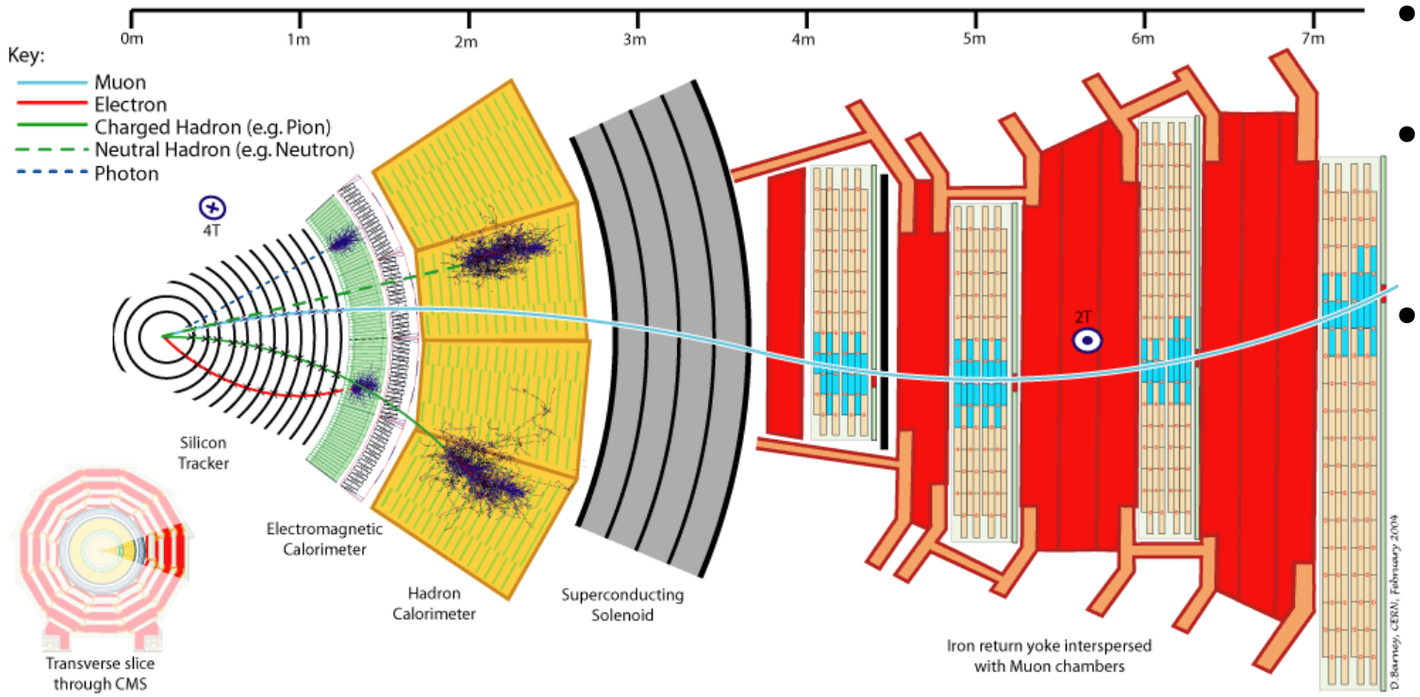
Artwork by Sandbox Studio, Chicago with Ana Kova

SungBin Oh, Jaesung Kim, Sihyun Jeon, Haneol Lee, John Almond, Un-ki Yang of Seoul National University with UC Riverside. On behalf of the CMS collaboration

Search for Heavy Neutrinos at the LHC with CMS Detector

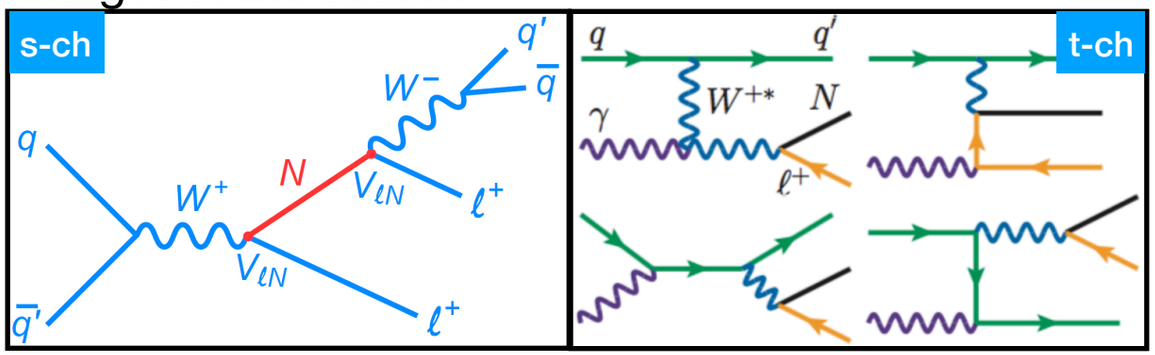
- The Large Hadron Collider (LHC)
  - A synchrotron which accelerates proton beam up to 6.5 TeV of energy
  - Bunches consist of ~10^{11} protons collide every 25 ns at the centre-of-mass energy 13 TeV

- The Compact Muon Solenoid (CMS) Detector
  - Cylindrical shape multilayered detector with superconducting solenoid of 3.8 T magnetic field



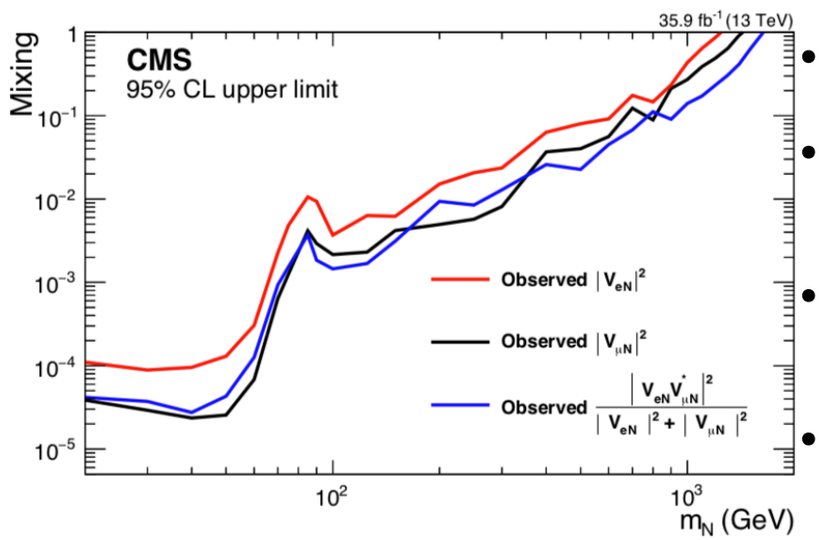
- Can reconstruct five categories of particles
  - μ, e, γ, charged hadron, and neutral hadron
- Momentum resolution
  - 0.5 % @ 50 GeV for e, μ
  - 10% @ 100 GeV for jets
- Trigger
  - 25 ns = 40 MHz event rate
  - ~ 100 kHz after level 1 triggers
  - ~ 1 kHz after high level triggers (HLT)
    - Store passed events into computing system

- Target of the search



  - Two same-sign lepton with at least one jet
    - To reduce background
  - Cross section as a function of mixing parameter square $|V_{lN}|^2$
  - Set limits on $|V_{lN}|^2$ if there is no excess

- Result



  - Searching range of N mass
    - 20 GeV to ~1 TeV
  - No significant excess is observed over background
  - World best direct limit
    - e for m(N) > 150 GeV
    - μ for m(N) > 100 GeV
  - Unique search with 13 TeV LHC run (RUN2)
    - eμ channel for whole of mass range