New limits on W_R from meson decays

Gustavo F. S. Alves

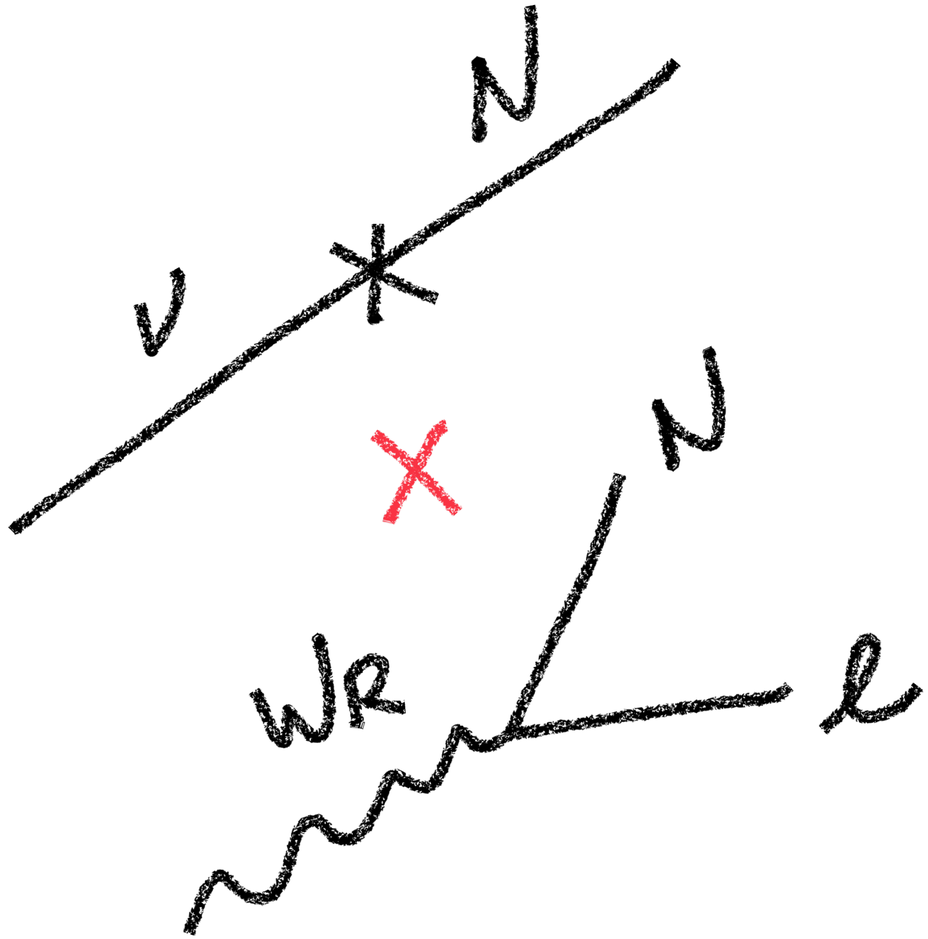
In collaboration with:
Chee Sheng Fong
Luighi P. S. Leal
Renata Zukanovich Funchal

FAPESP
FUNDAÇÃO DE AMPARO À PESQUISA DO ESTADO DE SÃO PAULO

IFUSP
Instituto de Física da USP

Outline:

- Motivation
- From mixture to right handed currents
- Results
- Conclusions



“V-A is the key”

- Weak interactions played a very important role to build the Standard Model (SM). Precisely, β-decays have:
  - Motivated a construction of a manifest parity-violating theory.
  - Hinted for new mediator scales.
- The status of the SM as a theory depends heavily on the V-A structure.
- That said, why is it parity violating?

S. Weinberg J. Phys. Conf. Ser. 196
C. S. Wu, E. Ambler, et al. Phys. Rev. 105, 1413
E. Fermi, Ric. Sc. 4, 491

“Will V+A be the key?”

- The Left-Right Symmetric Model (LRSM) is one of the simplest and best motivated extensions of the SM. Based on

$$SU(2)_L \otimes SU(2)_R \otimes U(1)_{B-L}$$

  - Features:
    - Additional gauge bosons W_R, Z_R - RH neutrinos are active under this sector!
    - Links parity violation of the SM to the breaking of the L-R symmetry.
    - Connects the point above to the generation of neutrino masses.

Pati and Salam, Phys. Rev. D 10, 275
R. N. Mohapatra and G. Senjanovic, Phys. Rev. Lett. 44
N. G. Deshpande, et. al, Phys. Rev. D 44
Senjanovic, arXiv:2011.01264

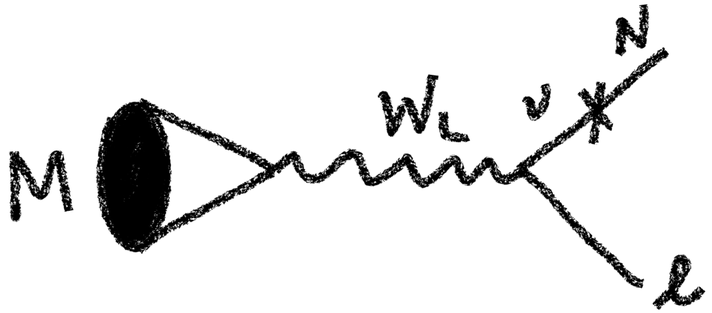
Testing the RH scale: Portals for the RH neutrino

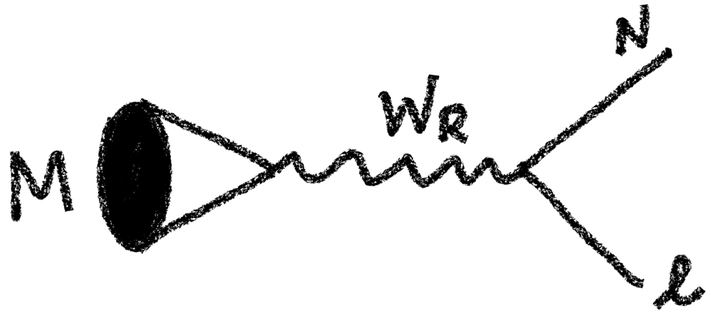
- The RH neutrino **is active** under the additional RH sector.

$$\mathscr{L}_R^{\mathrm{CC}} = -\frac{g_R}{\sqrt{2}}\left(\overline{N}U_{\mathrm{RR}}^{\dagger}\not{W}_R L_R + \overline{D}_R V_R^{\dagger}\not{W}_R U_R + \mathrm{h.c.}\right)$$

- This furnishes an **additional portal** that may compete with the production via mixture.
- We will assume a **degenerate spectra** for N such that U_{RR} drops out.

$$\Gamma(M \to lN) = (G_F^2 |\, U_{lN}|^2 + (G_F')^2) f(m_M, m_l, m_N)$$





Senjanovic and Tello, arXiv:1408.3835

Can the RH current dominate production?

- The active-sterile mixture depends on the mass generation mechanism.
- Benchmark scenario: LR model with a bidoublet and two scalar triplets.
  - We have type I and II seesaw contributions. Neutrino masses and mixings given by:

$$m_\nu = \underbrace{M_L^\dagger}_{m_{II}} - \underbrace{M_D M_R^{-1} M_D^T}_{m_I} \qquad |U_{lN}|^2 \sim m_I m_R^{-1}$$

J. Barry and W. Rodejohann, arXiv:1303.6324.
P. S. Bhupal Dev, S. Goswami, and M. Mitra, arXiv:1405.1399.
G. Bambhaniya, P. S. B. Dev, S. Goswami, and M. Mitra, arXiv:1512.00440.
S. Goswami and K. N. Vishnudath, arXiv:2011.06314.
D. Borah and A. Dasgupta, arXiv:1606.00378.
V. Tello, M. Nemevsek, F. Nesti, G. Senjanovic, and F. Vissani, arXiv:1011.3522.
G. Li, M. Ramsey-Musolf, and J. C. Vasquez, arXiv:2009.01257.

Can the RH current dominate production?

- Competing contributions:

$$G_F^2 |\, U_{lN}|^2 \times (G_F')^2$$

- For type I dominance we would have to satisfy:

$$m_\nu < 7 \times 10^{-2}\ \text{eV} \left(\frac{\text{m}_\text{N}}{1\ \text{MeV}} \right) \left(\frac{5\ \text{TeV}}{\text{m}_{\text{W}_\text{R}}} \right)^4 \left(\frac{\text{g}_\text{R}}{\text{g}_\text{L}} \right)^4$$

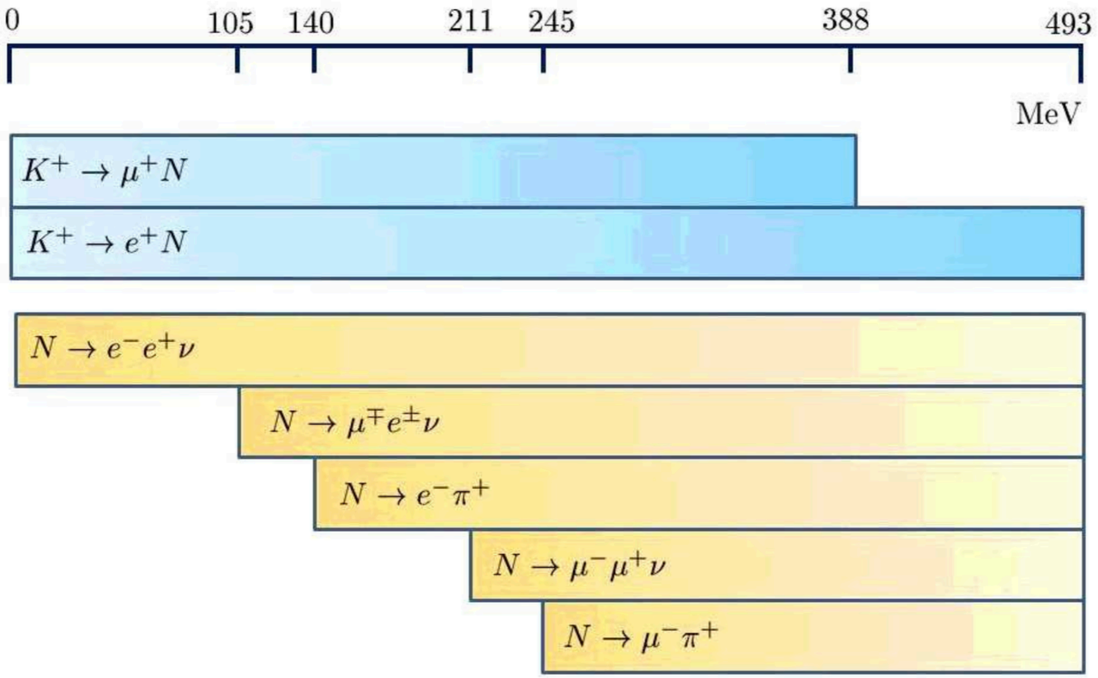
- For type II mixing is always subdominant.

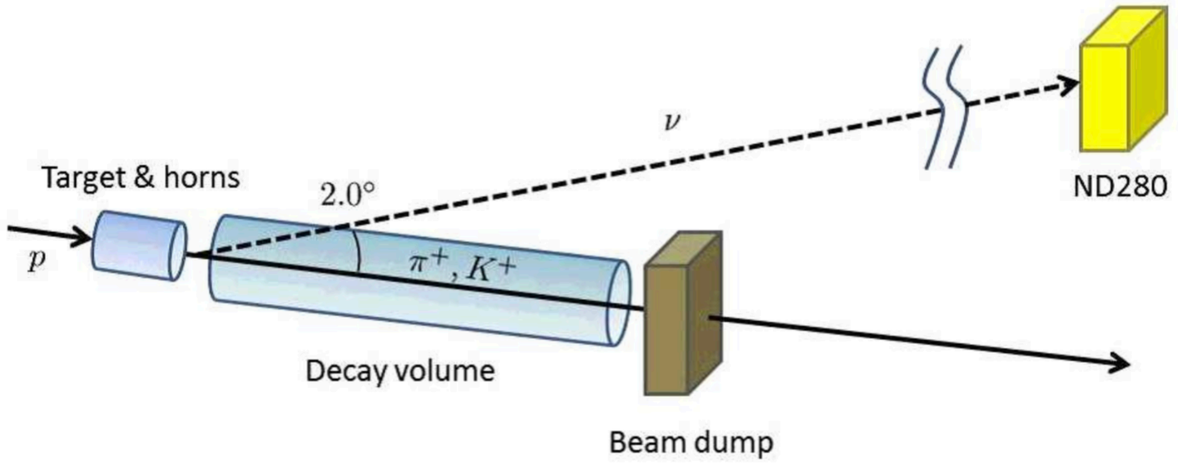
RH neutrino searches at the MeV scale

- Primary mode of production inherited from the light neutrino production mode. Types of searches:
  - **Visible searches**: Heavy neutrinos decay into visible particles.
  - **Invisibles searches**: Use energy distribution of the measured particles.
  - **Decay ratios**: Rate of meson decays change in the presence of a massive neutrino.

Visible searches

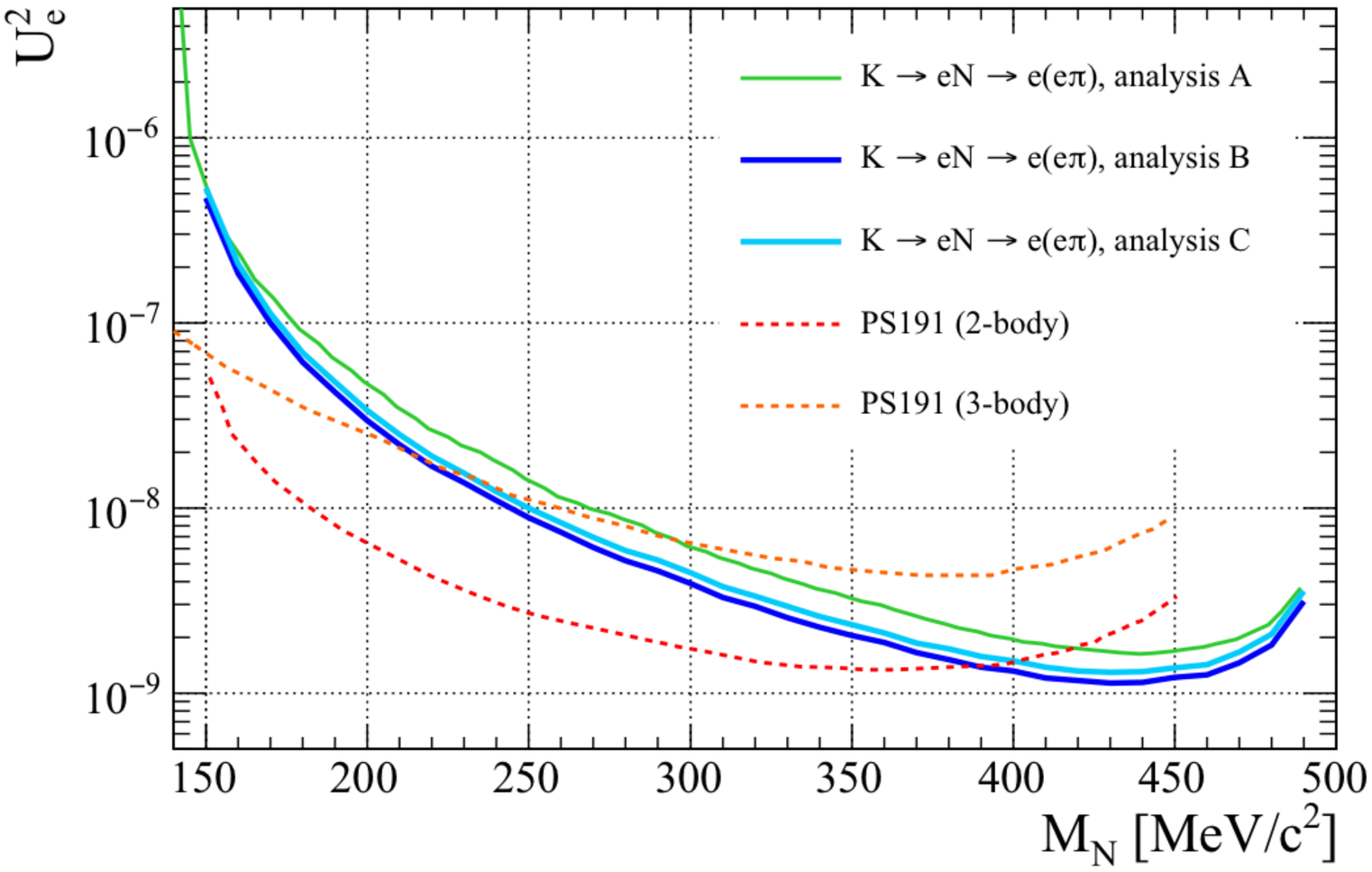
- Look for visible decays of heavy neutral leptons.
- Example: T2K ND280.





Abe et. al, arXiv:1902.07598
Asaka et. al., arXiv:1212.1062

T2K ND280 search

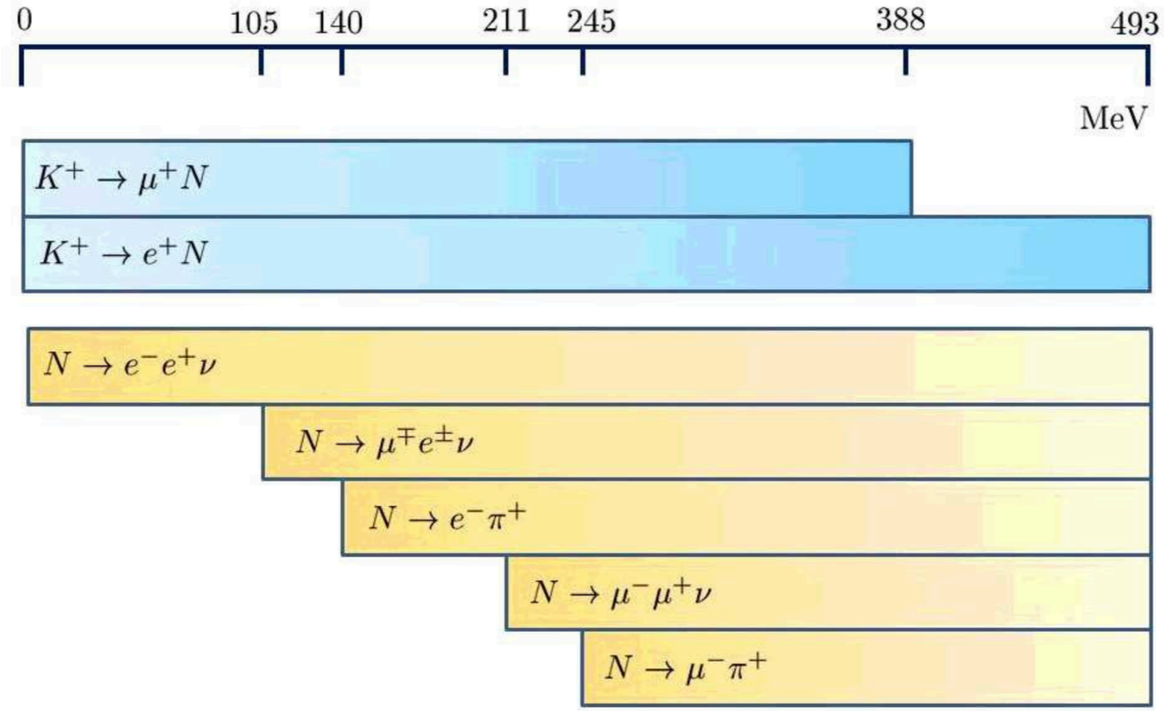


Abe et. al, arXiv:1902.07598

Reanalysis for RH current dominance

To Do:

- ☐ Are all production channels available?
- ☐ Phase space and kinematics implemented accordingly?
- ☐ Detection channels available?

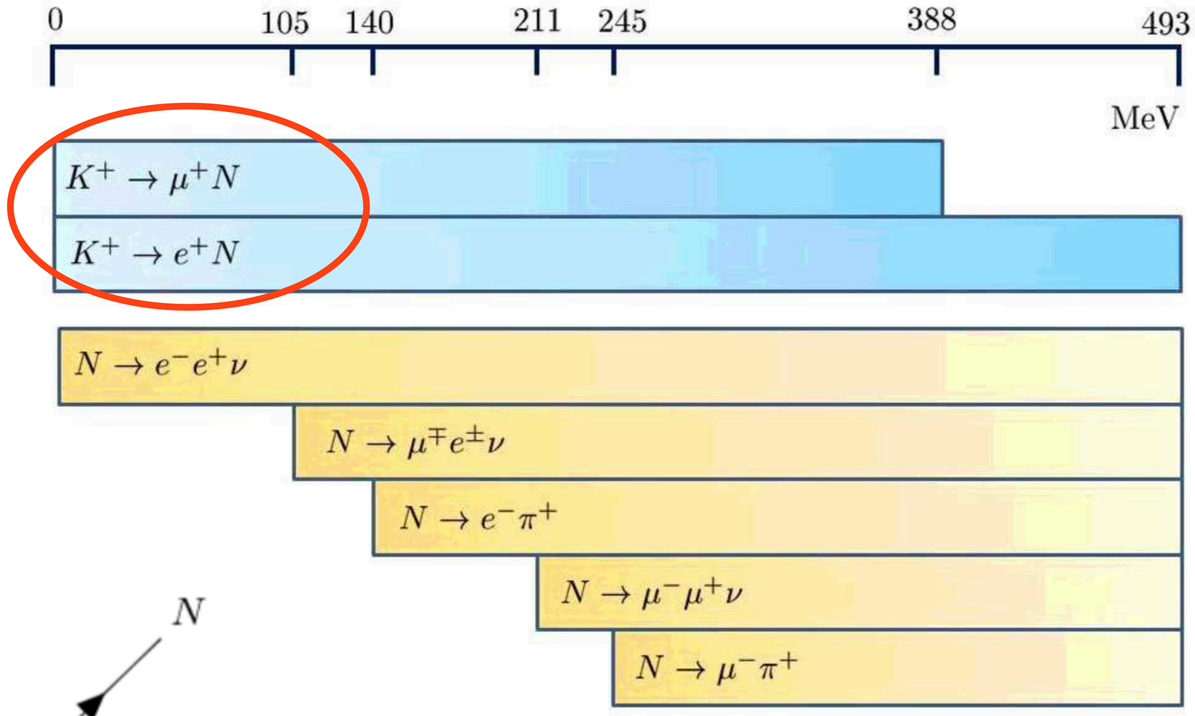


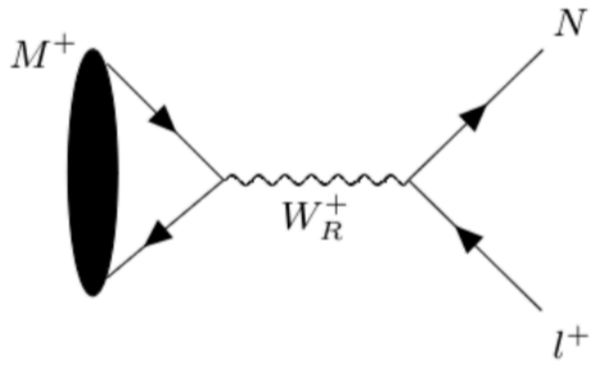
Abe et. al, arXiv:1902.07598
Asaka et. al., arXiv:1212.1062

Reanalysis for RH current dominance

To Do:

- [x] Are all production channels available?
- [ ] Phase space and kinematics implemented accordingly?
- [ ] Detection channels available?



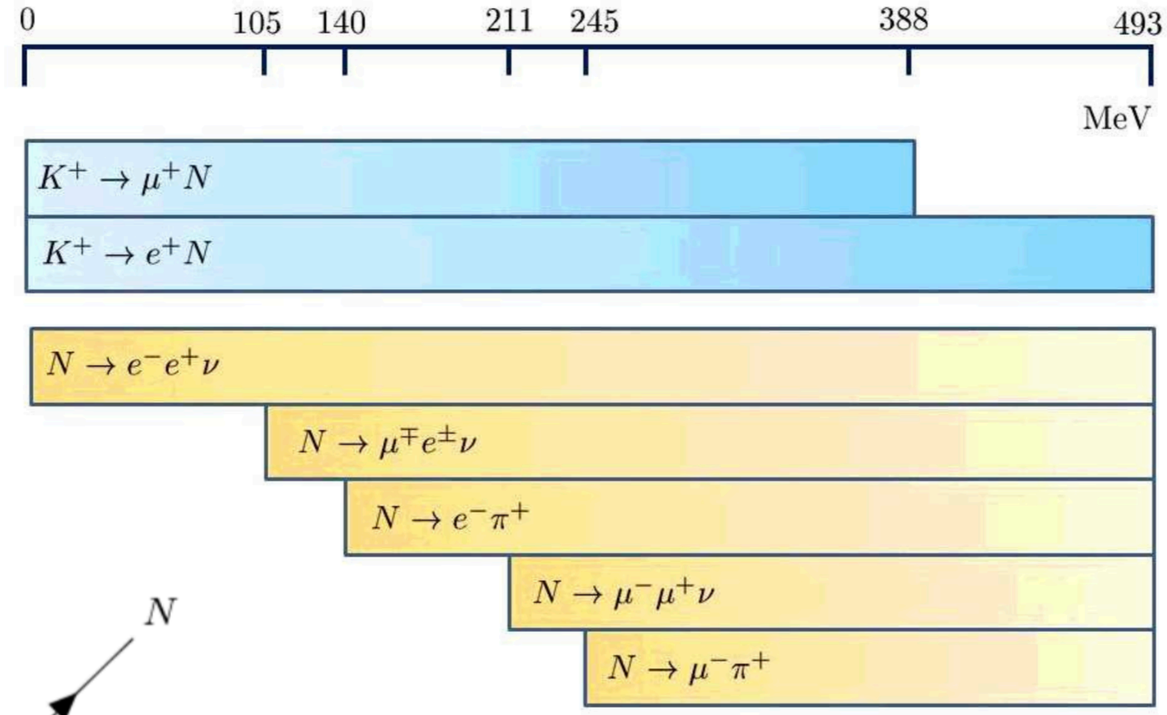


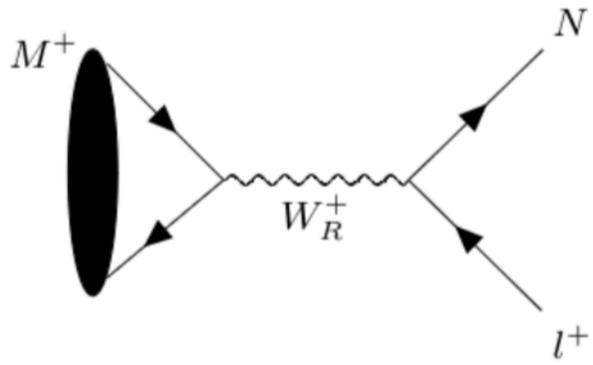
Abe et. al, arXiv:1902.07598
Asaka et. al., arXiv:1212.1062

Reanalysis for RH current dominance

To Do:

- [x] Are all production channels available?
- [x] Phase space and kinematics implemented accordingly?
- [ ] Detection channels available?



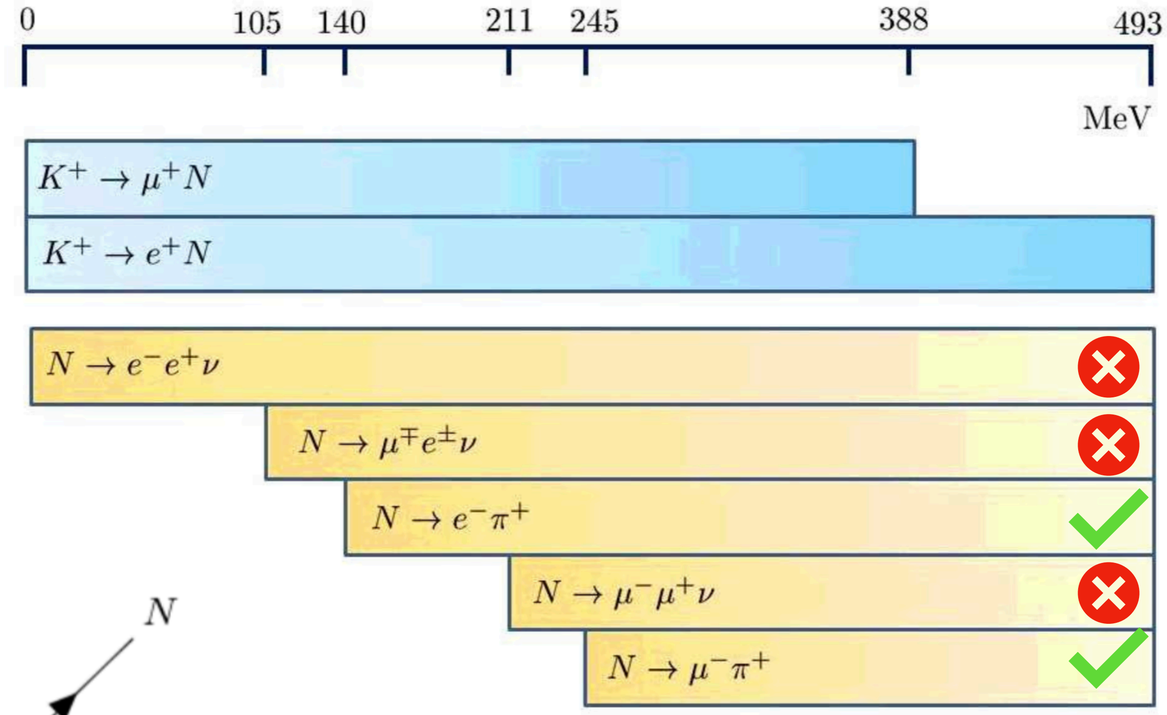


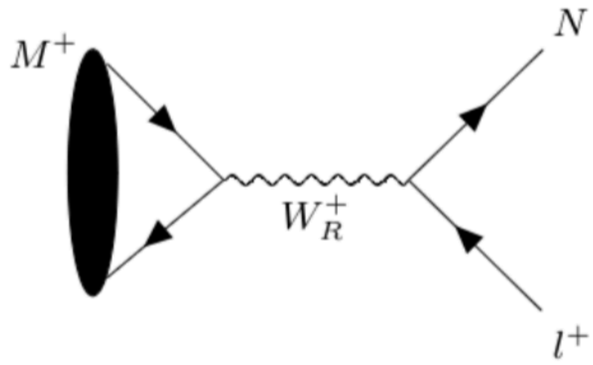
Abe et. al, arXiv:1902.07598
Asaka et. al., arXiv:1212.1062

Reanalysis for RH current dominance

To Do:

- [x] Are all production channels available?
- [x] Phase space and kinematics implemented accordingly?
- [x] Detection channels available?

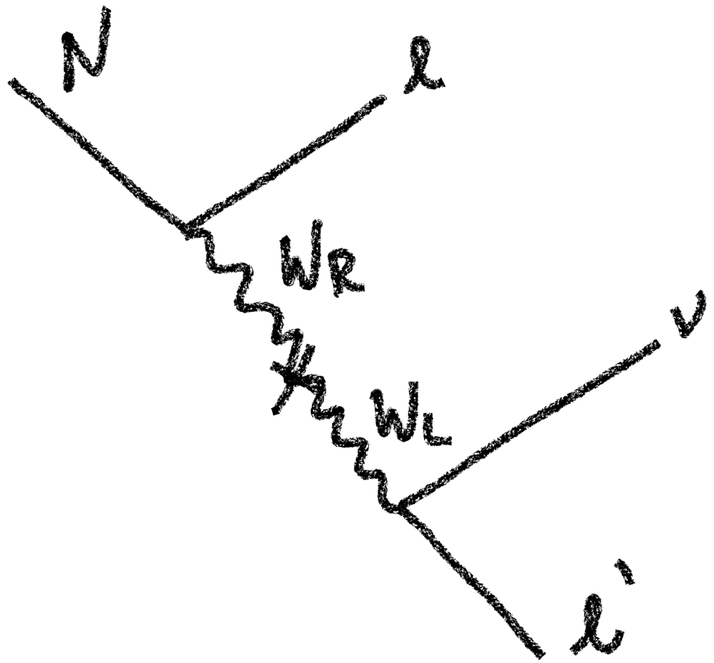


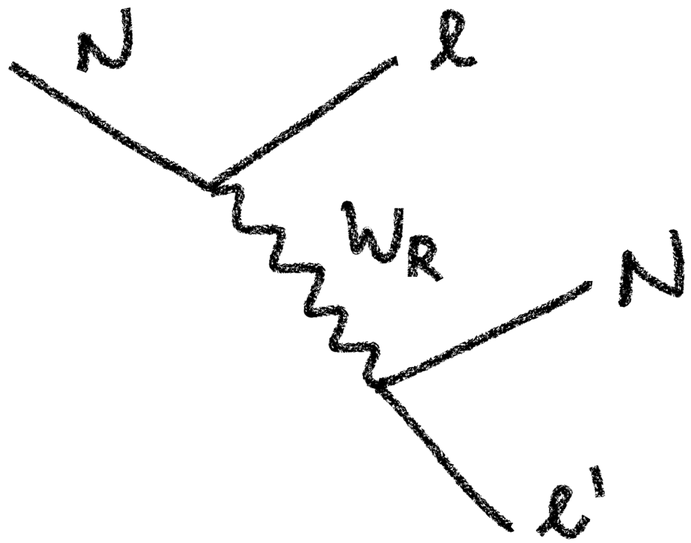


Abe et. al, arXiv:1902.07598
Asaka et. al., arXiv:1212.1062

Reanalysis for RH current dominance

- Similar analysis for BEBC.
- Unfortunately we can’t use CHARM for charged current production as they have only considered three body final states.





Grassler et al., Nucl. Phys. B 273
Cooper-Sarkar et al., Phys. Lett. B 160
Bergsma et al., Phys. Lett. B 166

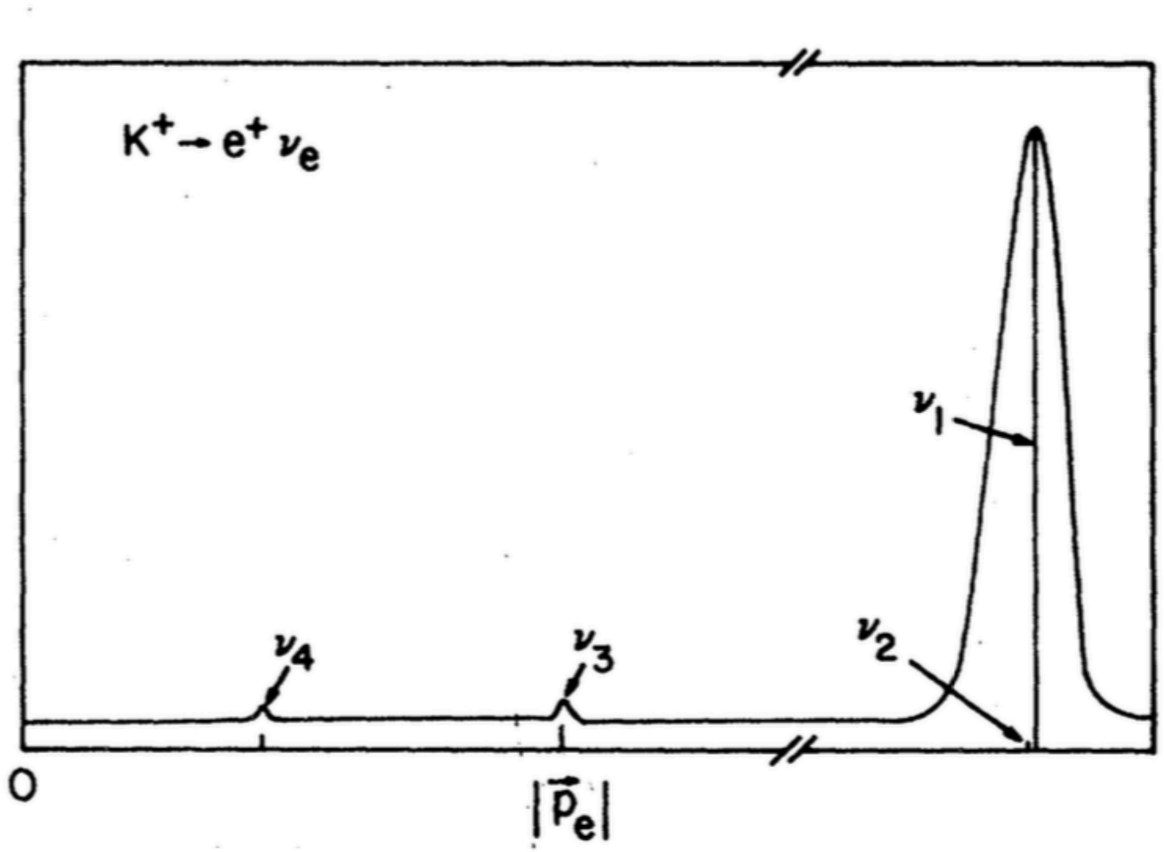
Invisible searches

- Emission of massive neutrinos manifest itself indirectly through peaks in the energy spectrum.
- The idea is to compare the experimental ratio with the SM calculation:

$$B(M^+ \to e^+ N) = B^{\mathrm{SM}}(M^+ \to e^+ \nu_e)\rho_e^{MN} |\, U_{lN}|^2$$

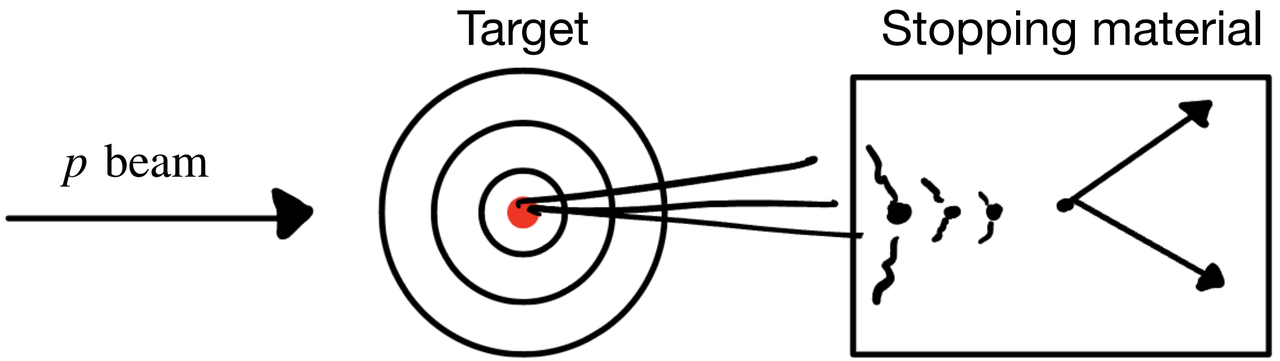
$$\downarrow$$

$$B(M^+ \to e^+ N) = B^{\mathrm{SM}}(M^+ \to e^+ \nu_e)\rho_e^{MN} \left(\frac{G_F'}{G_F}\right)^2$$



Shrock Phys. Rev. D 24

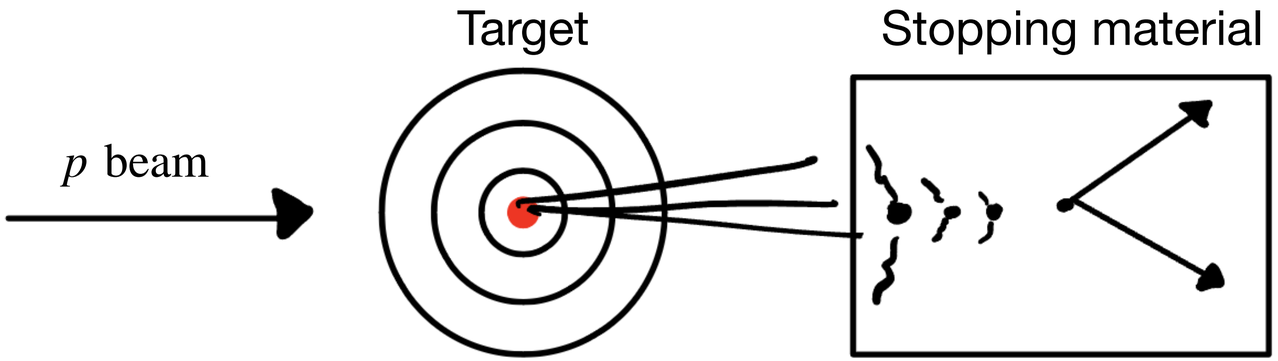
Bird’s eye view of the experiment



For $\pi \to e^+\nu_e$ with SM neutrinos:

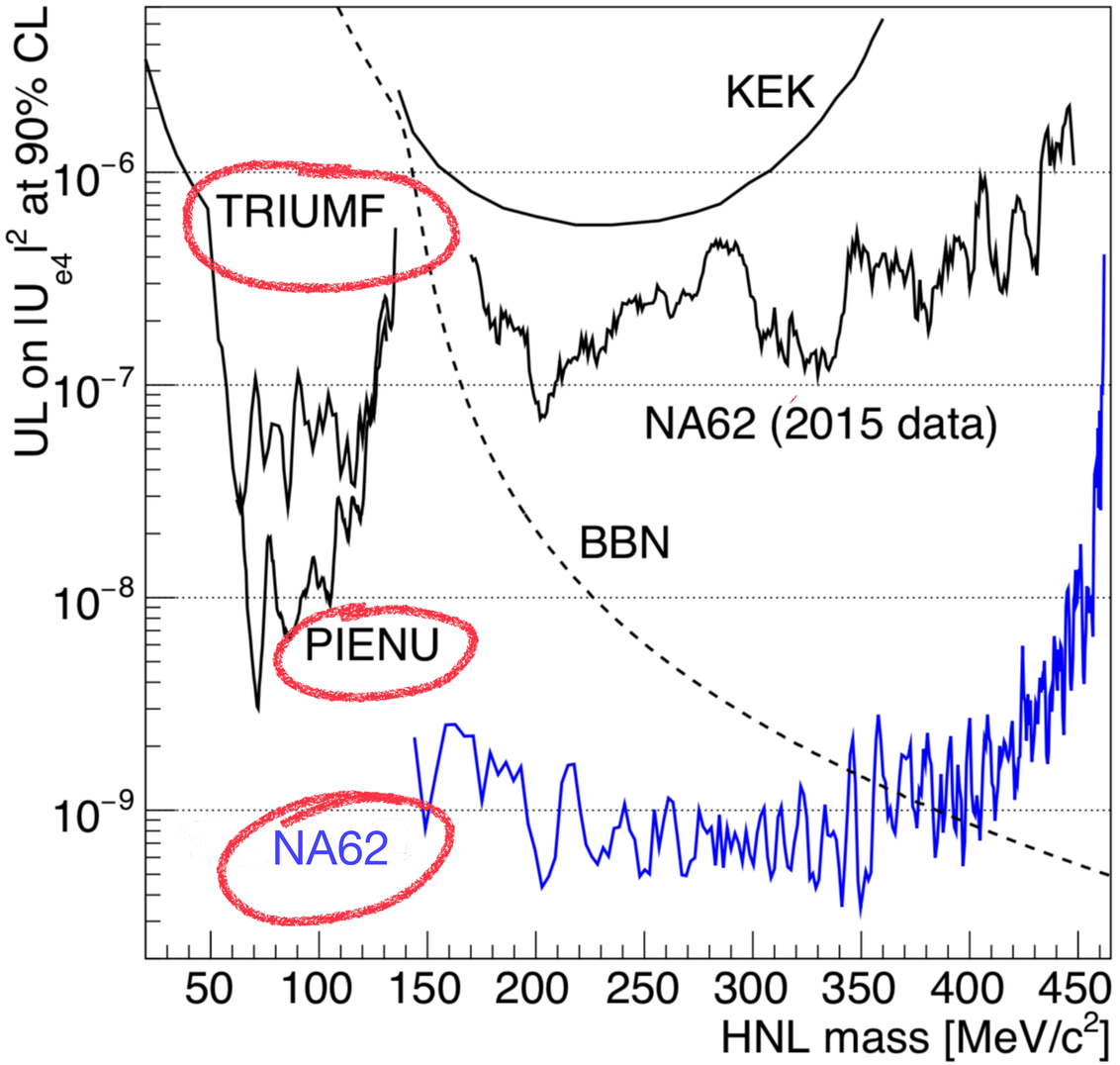
$$E_e = \frac{m_\pi^2 + m_e^2 - m_\nu^2}{2m_\pi} \sim 69.8 \text{ MeV}$$

Bird's eye view of the experiment



- Decay in flight can also be studied.
- Main background comes from $\pi \rightarrow \nu_\mu \mu$, followed by $\mu \rightarrow e \nu_e \nu_\mu$ decays.

Nice idea nice constraints



NA62 collaboration, arXiv:2005.0957
PiENu, arXiv:1505.02737
Britton et al., Phys. Rev. D 46

Meson Decay Ratios

- The decay $\pi \to e\nu$ is helicity suppressed but $\pi \to eN$ is not!
- The idea is to compare the theoretical prediction and experimental value for the ratio:

$$R_{e/\mu}^{\mathrm{SM}} = \frac{B(M \to e\nu_e)}{B(M \to \mu\nu_\mu)}$$

- Heavy neutral lepton emission would impact the value!

$$R_{e/\mu} = \frac{1 + R_{N/\nu_e}}{1 + R_{N/\nu_\mu}} R_{e/\mu}^{\mathrm{SM}} \qquad R_{N/\nu_\alpha} = \frac{B(M \to l_\alpha N)}{B(M \to l_\alpha \nu_\alpha)}$$

Meson Decay Ratios

- We considered the PDG experimental values:

$$R_{e/\mu}^{PDG}(\pi) = (1.2327 \pm 0.0023) \times 10^{-4}$$

$$R_{e/\mu}^{PDG}(K) = (2.488 \pm 0.009) \times 10^{-5}$$

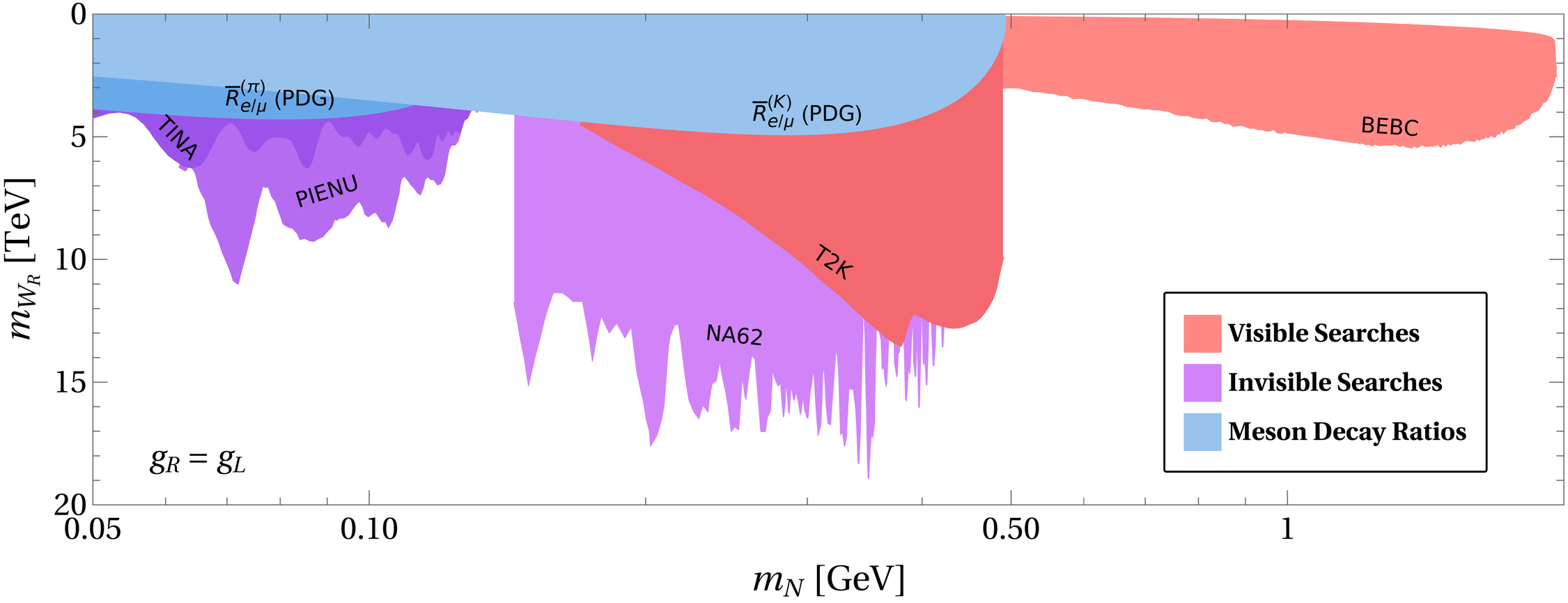
- For the theoretical input we used the SM prediction:

$$R_{e/\mu}^{PDG}(\pi) = (1.2352 \pm 0.0001) \times 10^{-4}$$

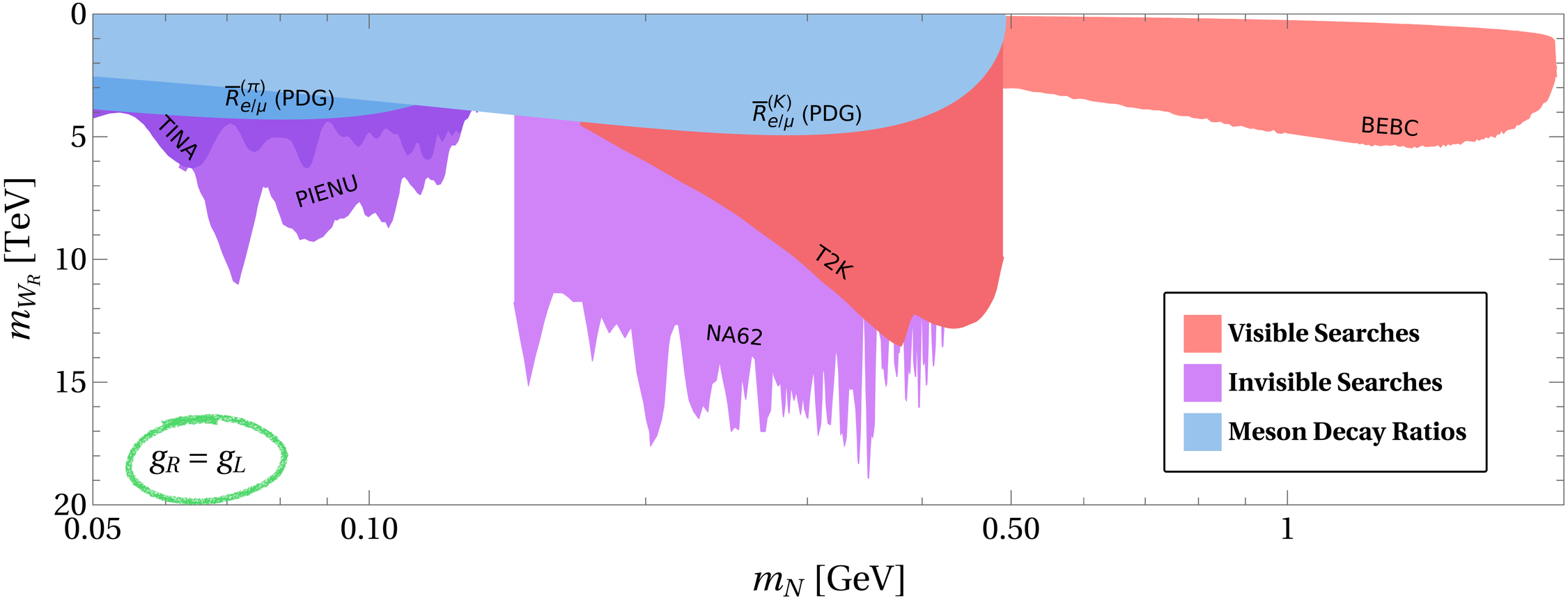
$$R_{e/\mu}^{PDG}(K) = (2.477 \pm 0.001) \times 10^{-5}$$

Cirigliano and Rosell, Phys. Rev. Lett. 99.
Marciano and Sirlin, Phys. Rev. Lett. 71.

Constraints on a RH current

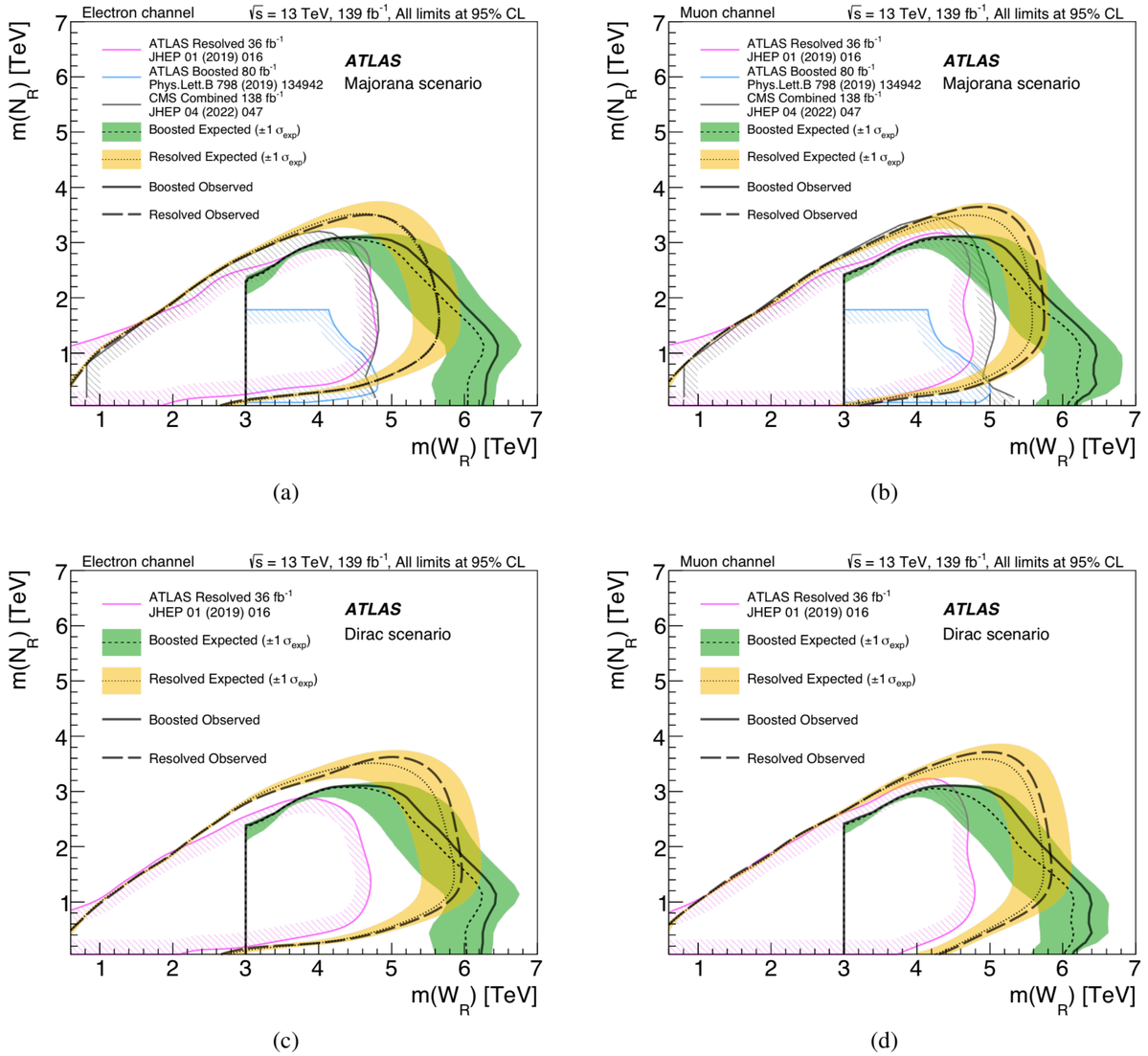


Constraints on a RH current



Comparison to the LHC

- LHC: Best bounds on m_{W_R}, for HNL in the GeV-TeV mass range.
- Loose sensitivity for smaller masses.
- Their bound extends up to $m_{W_R} < 6.4\ \mathrm{TeV}$.
- Neutrino experiments kick in for lighter HNL's!



Conclusions

- We have used low energy pseudoscalar mesons leptonic decays to constrain the mass of a right hand gauge boson.
- Our bounds cover the mass range $50 \leq m_N/MeV \leq 1900$ and are complementary to the LHC bounds on m_{W_R} for lighter neutral leptons.
- Different portals can be studied in this framework!
- Experiments such as ICARUS, MicroBooNE, SBND, DUNE, Belle II, SuperKEKB and HIKE can constrain even more this scenario in the future.