# Sterile neutrinos at TLEP

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FCC-ee/TLEP physics workshop (TLEP7)

# 5 types of sterile neutrinos

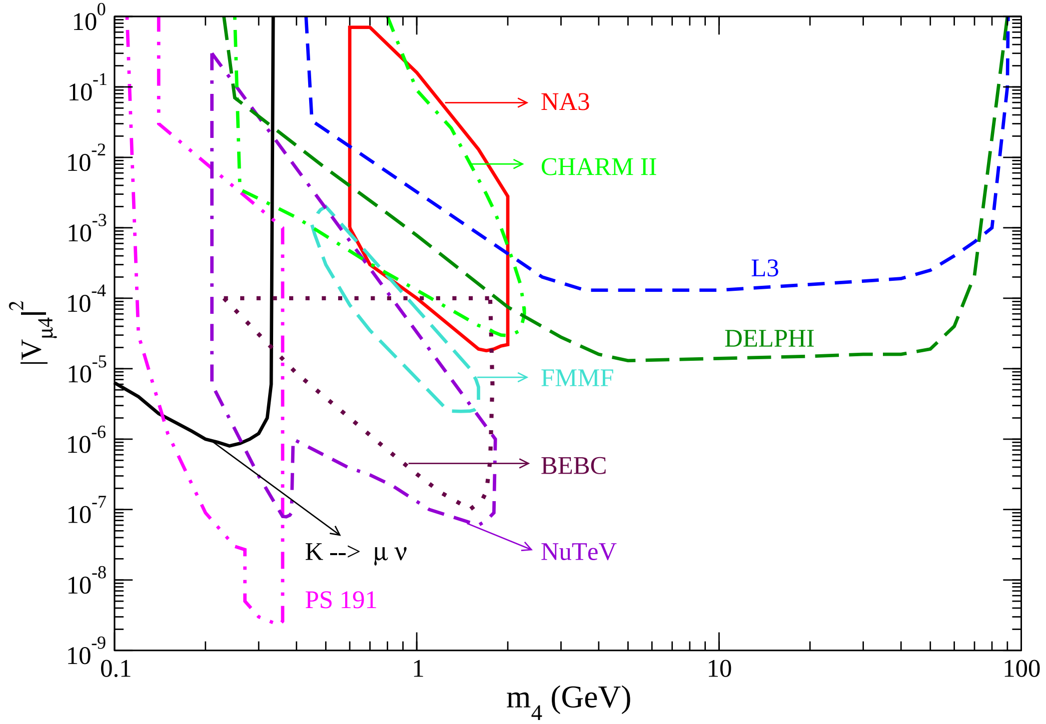
sterile neutrino for $M \gg 1$ eV = HNL - heavy neutral lepton

- just so HNL : if there are left-handed neutrinos why not to have right-handed neutrinos?
- eV scale sterile neutrinos, motivated by short base-line neutrino anomalies (LSND, etc).
- HNL, giving rise to active neutrino masses
- HNL, giving rise to active neutrino masses and leading to baryon asymmetry of the universe
- HNL, giving rise to active neutrino masses, leading to baryon asymmetry of the universe, and to dark matter

Interesting mass range: $M_N < M_Z$, to search for in $Z$ -decays.

Interaction strength : mixing angle $U^2$

# Survey of constraints on just so HNL




From arXiv:0901.3589, Atre et al

# HNL and neutrino masses

Notations: $M_D$ - Dirac mass, $M$ - Majorana mass, $F$ - Yukawa coupling, $v$ - Higgs vev

One flavour see-saw formula:

$$m_\nu \simeq \frac{m_D^2}{M} \simeq \frac{F^2 v^2}{M} = U^2 M \quad \Longrightarrow \quad U^2 = \frac{m_\nu}{M} \simeq 10^{-10} \frac{GeV}{M}$$

Naive expectation: If HNL gives rise to neutrino masses, it would not be possible to find them at TLEP, even though the number of $Z$-decays will be 5 orders of magnitude larger than at LEP ($10^{12}$ versus $10^7$).

LEP limit: $U^2 < few \times 10^{-5}$.

# Naive expectation is wrong!

We need at least 2 HNL to explain atmospheric and solar mass differences.

Consequence: instead of equality we have only lower bound!

$$U^2 > \frac{m_\nu}{M} \simeq 10^{-10}\frac{GeV}{M}$$

# Physics of large mixing angles

MS '06; Kersten and Smirnov '07:

Consider SM + one extra massive Dirac spinor $\Psi$, which is singlet with respect to SM.

$$L = L_{SM} + \bar{\Psi} i \partial_\mu \gamma^\mu \Psi - F_\alpha \, \bar{L}_\alpha \Psi H - M \, \bar{\Psi} \Psi + h.c.,$$

Symmetry: lepton number conservation. For any $F_\alpha$ and $M$ all active neutrinos are massless.

Small symmetry breaking terms $\Longrightarrow$ small active neutrino masses :

$$\Delta L = f_\alpha \, \bar{L}_\alpha \Psi^c H - m \, \bar{\Psi} \Psi^c + h.c.,$$

Active neutrino masses:

$$m_\nu \simeq \frac{F v^2 \times f}{M} + \frac{F^2 v^2 \times m}{M^2}$$

Consequence: any increase of experimental sensitivity may lead to discovery of HNL responsible for active neutrino masses!

Potential TLEP limit: $U^2 < \text{f}ew \times 10^{-10}$ for a range of masses above $20$ GeV, see below

# HNL, $\nu$ masses and BAU

Akhmedov, Rubakov, Smirnov ’98; Asaka, MS ’05

HNL oscillations as a source of baryon asymmetry. Qualitatively:

- HNL are created in the early universe and oscillate in a coherent way with CP-breaking.
- Lepton number from HNL can go to active neutrinos.
- The lepton number of active left-handed neutrinos is transferred to baryons due to equilibrium sphaleron processes.

# Sakharov condition

Rate of HNL equilibration $\Gamma \simeq \kappa F^2 T$ must be smaller than the rate of the Universe expansion at the sphaleron freeze-out $T = T_{sph} \simeq 130$ GeV, $H \simeq T^2/M_0$, $M_0 \sim M_{Pl}$ ($\kappa \simeq 3 \times 10^{-6}$ - some number following from solution of kinetic equations in the early universe):

$$\kappa F^2 \left(1 - \frac{M^2}{M_W^2}\right)^2 T_{sph} < \frac{T_{sph}^2}{M_0}$$

Numerically, $F < 8 \times 10^{-6}$, and

$$U^2 < 2 \times 10^{-6} \left(\frac{GeV}{M}\right)^2 \left(1 - \frac{M^2}{M_W^2}\right)^2$$

# Expectations for TLEP

Processes: $Z \to N\nu, \quad N \to l q \bar{q}$ (lepton + meson, lepton + 2 quark jets),

$$BR(Z \to \nu N) \simeq BR(Z \to \nu\nu) U^2, \qquad \Gamma_N \simeq \frac{G_F^2 M^5}{192\pi^3} U^2 A$$

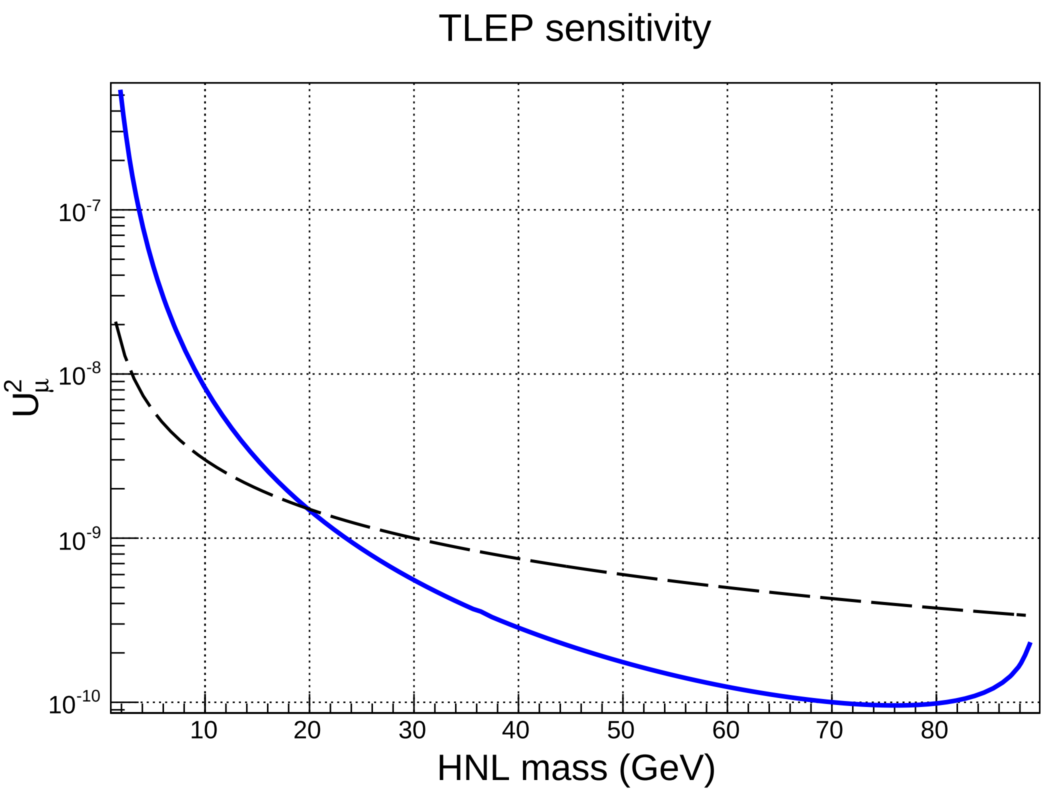
Coefficient A counts the number of open channels, $A \sim 10$ for $M > 10$ GeV

Assumptions: $10^{12}$ Z-decays in 3 m detector.

- “short lived” N: decay length < 3 m $\Longrightarrow$ constraint on $U^2$ may go down to $U^2 < 10^{-10}$ as the sensitivity will grow as the number of Z-decays! This works for $M \gtrsim 20$ GeV.
- “long lived” N: decay length exceeds the size of the detector $\Longrightarrow$ constraint on $U^2$ may go down to $U^2 < 4 \times 10^{-8}$ as the sensitivity will grow as the square root of the number of Z-decays. This works for lighter HNL.

# Sensitivity plot, very preliminary

Elena Graverini, Nico Serra, Walter Bonivento, 20.06.2014



# Sensitivity plot, very preliminary

MS, 20.06.2014

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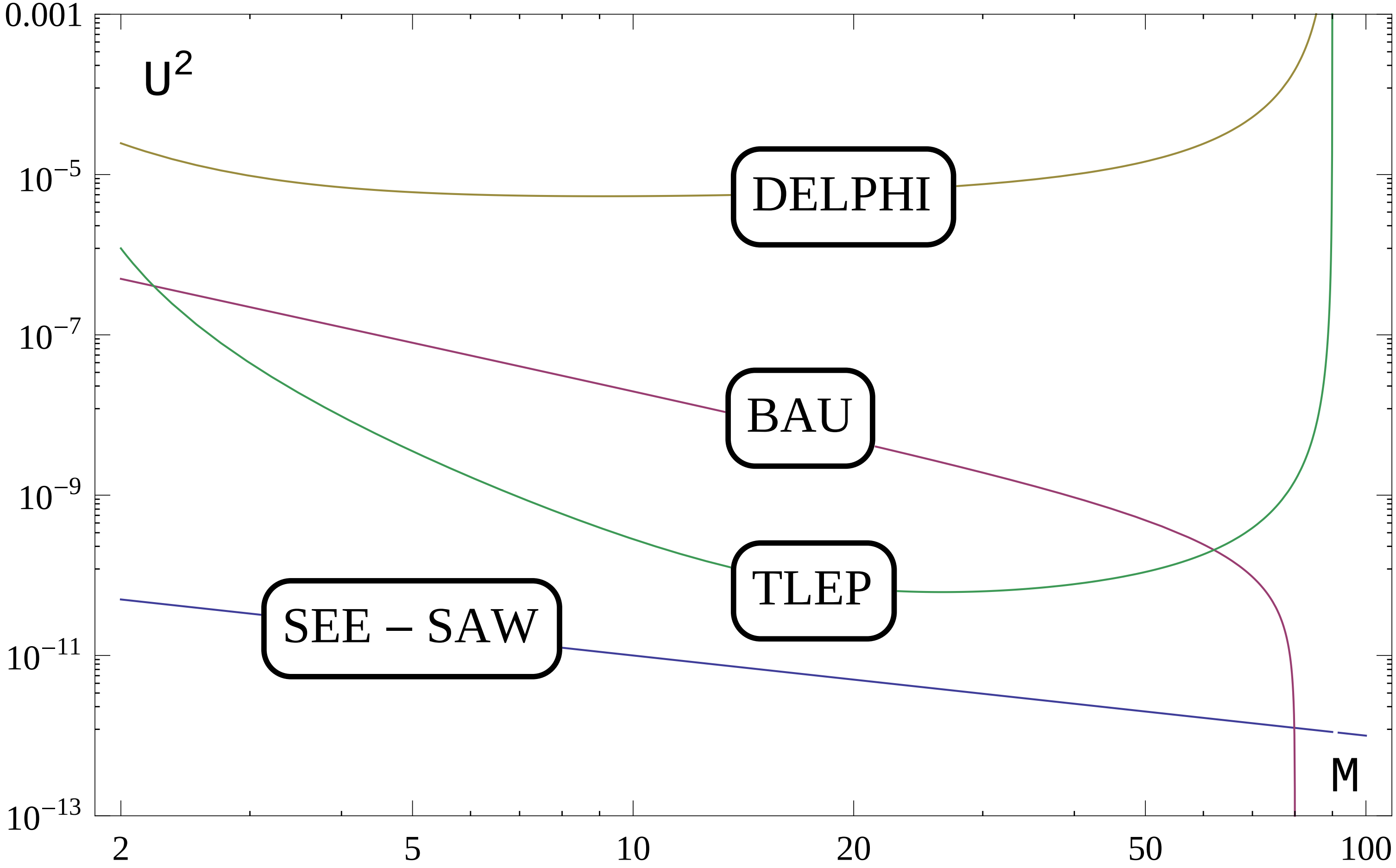
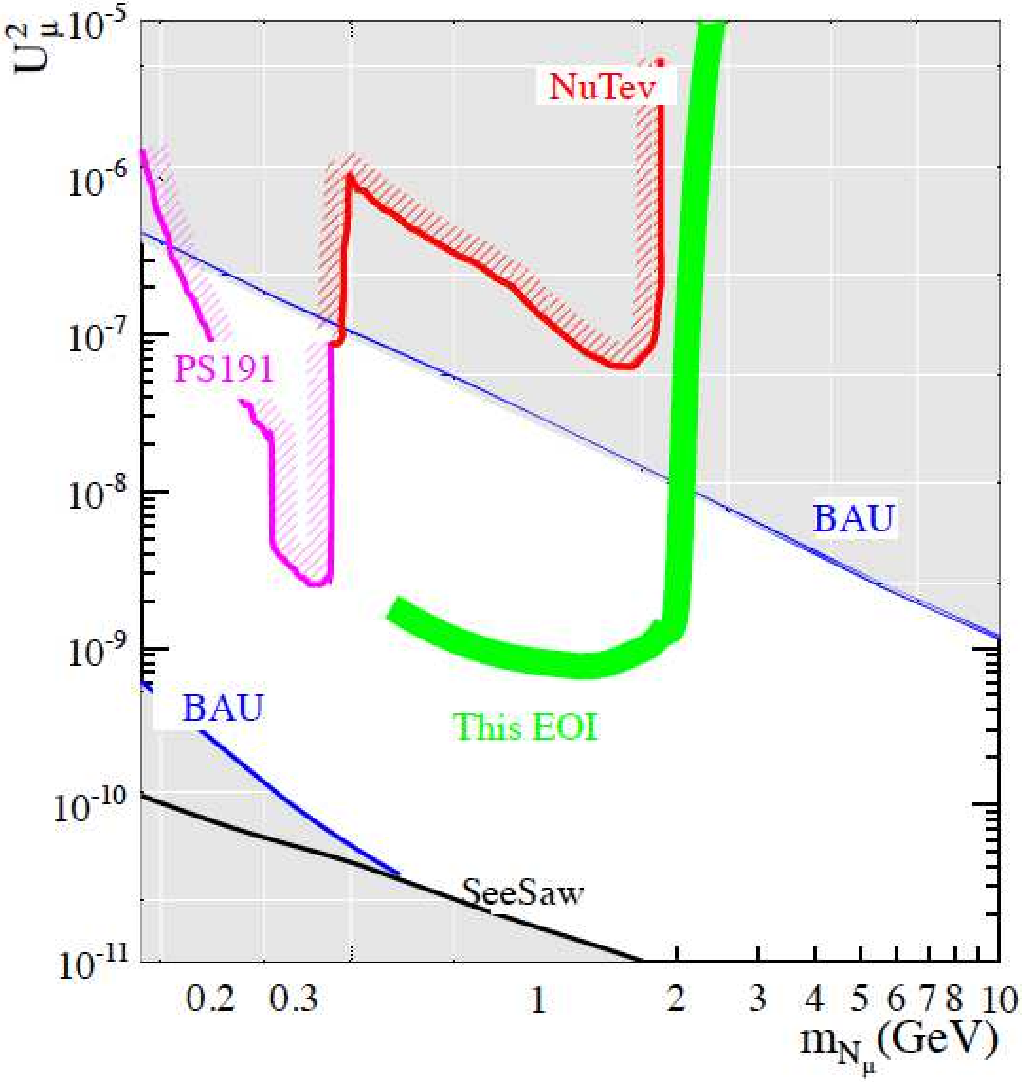


# SHIP sensitivity



# Conclusions

- TLEP can reveal the origin of neutrino masses if $M > 2$ GeV and the origin of baryon asymmetry of the Universe if $M > 3$ GeV (very indicative number!!!)
- Fix target experiment SHIP and collider experiments at TLEP can search for HNL in complementary regions: for SHIP $M < 2$ GeV .