New constraints on HNLs from the BEBC beam dump experiment

Giacomo Marocco
University of Oxford

FIPs 2022

Introduction

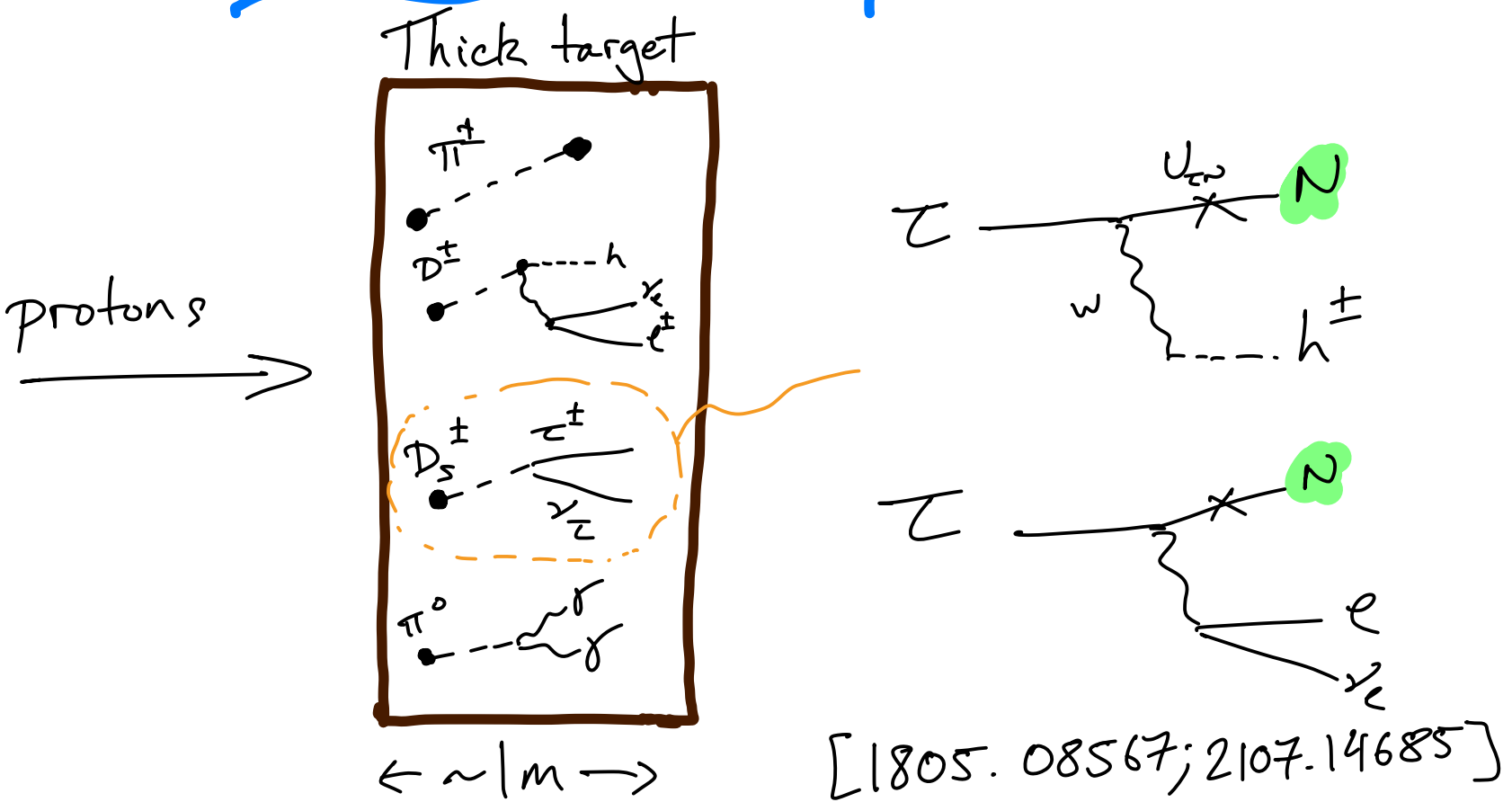
- How do we find new, light, weakly coupled states?
  - ↳ Go to intensity frontier!
- What can upcoming forward physics experiments (@ CERN, FNAL, etc.) discover?
  - ↳ Look for HNLs (+ other dark states) at past beam dump experiments e.g. BEBC

Heavy Neutral Leptons

- New SM singlet N
  - ↳ One of few SM – BSM renormalisable portals: $(L\tilde{\Phi})N$ — neutrino masses?
- Mixing with 3rd generation least constrained

$$\nu_\tau = \sum_{i=1}^{3} U_{\tau i}\,\nu_i + U_{\tau N}\,N$$

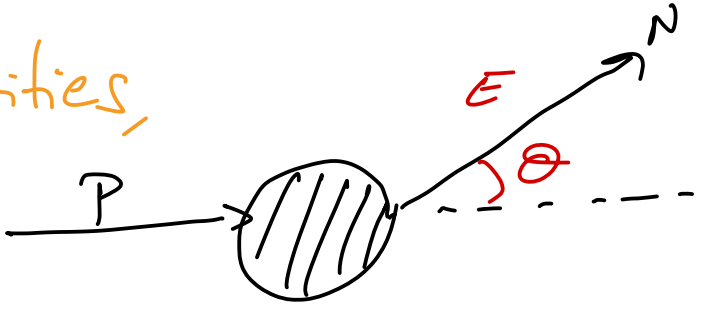
Beam dump production



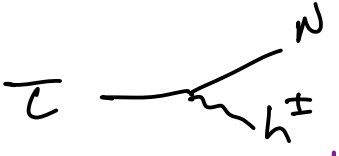
[1805.08567; 2107.14685]

HNL Spectrum

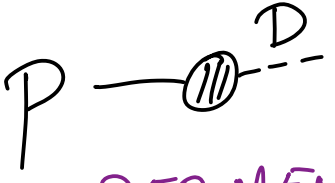
- To calculate sensitivities, need $\frac{d^2\sigma_N}{dE\,d\theta}$



↳ Decay distributions ⟶ THEORY!



↳ Parent distributions ⟶ EXPERIMENT!



- Reduce systematic uncertainty in total ν flux

inferred from measured ν_e flux

$$\frac{N_\nu}{N_{\nu_e}} = \frac{\sigma(pX \to \nu X)}{\sigma(pX \to \nu_e X)}$$

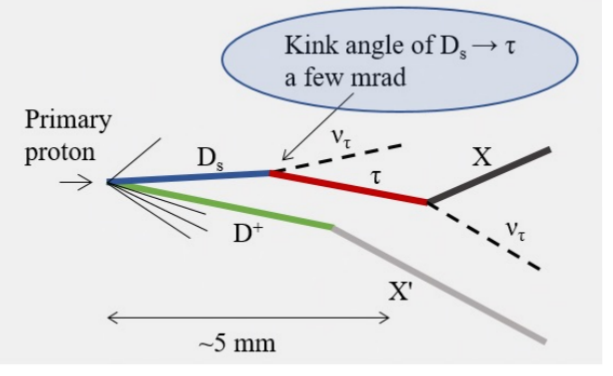
- Experimentally fit parent D distribution

$$\frac{d^2\sigma_D}{dp_T^2\, dx_F} \sim e^{-b p_T^2} (1 - |x_F|)^n$$

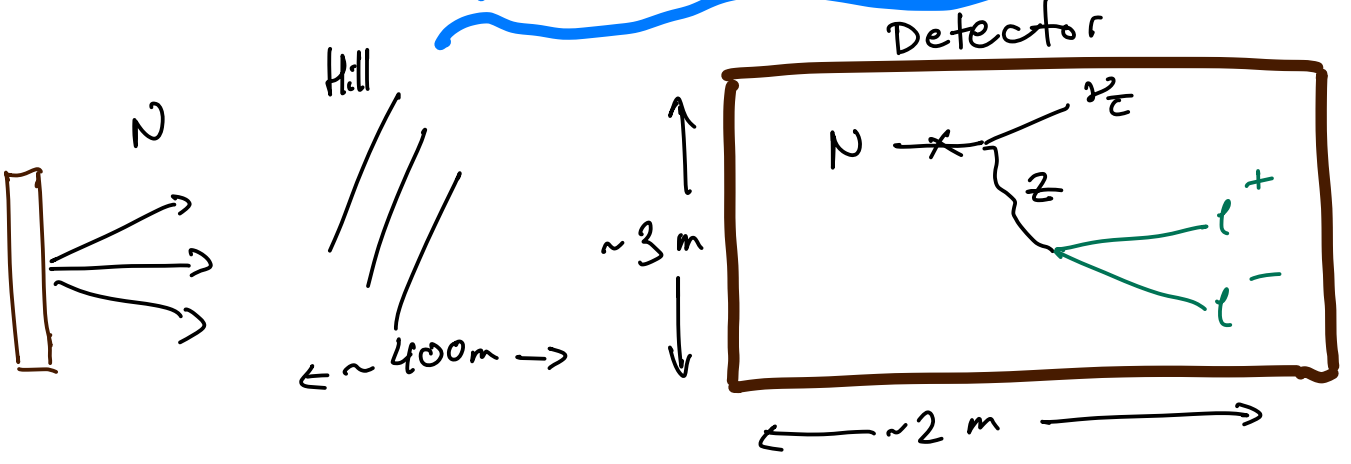
b, n for $pCu \to D_s$

assumed same as for $pCu \to D^\pm$.

DsTau NA65



HNL detection



$$P_{det} = P_{survival} \cdot \epsilon_{geom} \cdot P_{decay} \cdot \Sigma_{det}$$

very model-dependent — new Z'? decay to dark states?

Big European Bubble Chamber
CERN SPS beam dump (1982)

- 11.5 tonnes of H_2–Ne mix
- 2.72×10^{18} POT @400GeV on Cu
- On-axis (406m from dump)
- Dedicated new physics analyses — excellent background rejection + detector efficiencies

SEARCH FOR HEAVY NEUTRINO DECAYS IN THE BEBC BEAM DUMP EXPERIMENT

WA66 Collaboration

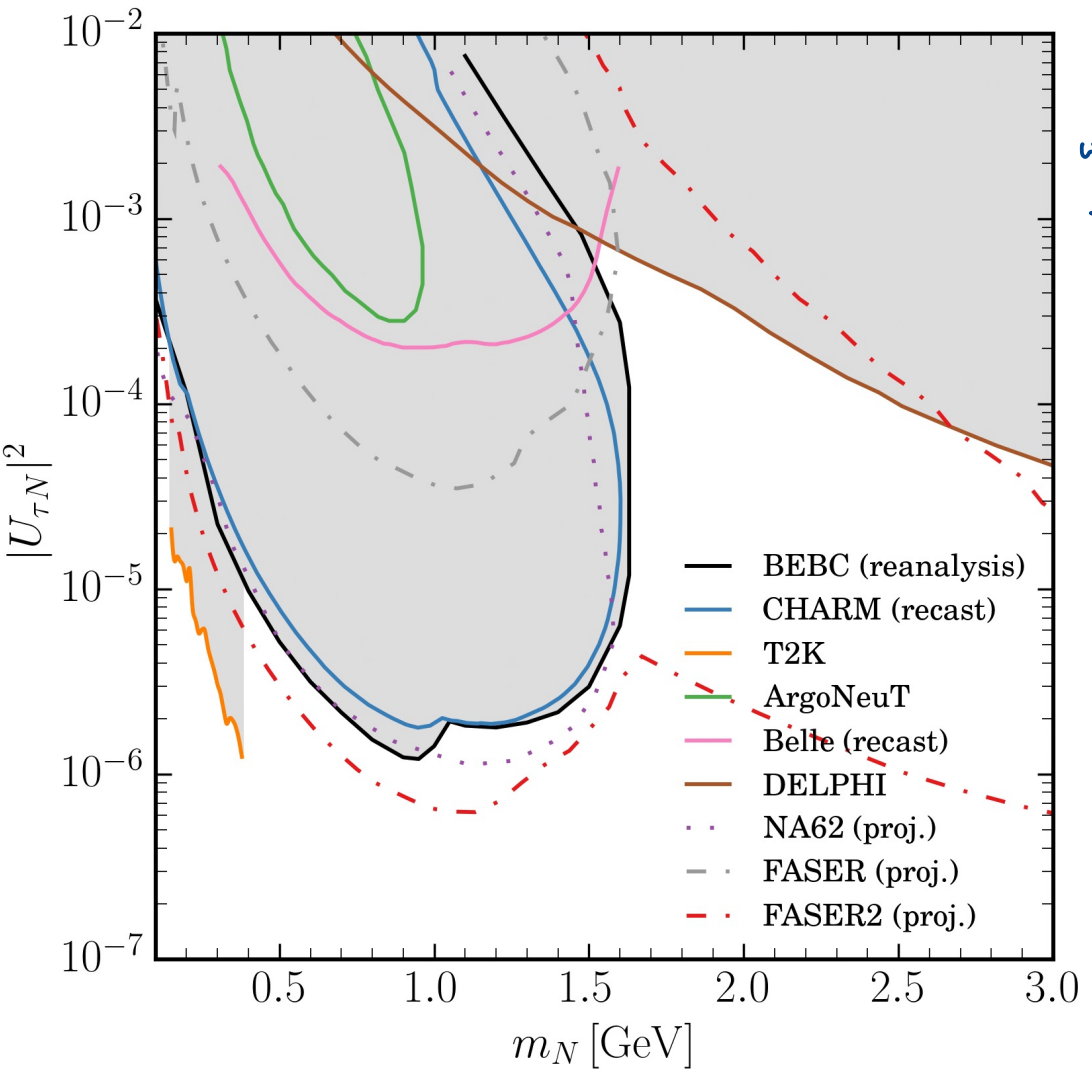
A.M. COOPER-SARKAR [a,1], S.J. HAYWOOD [a,2], M.A. PARKER [a], S. SARKAR [a,3,4], K.W.J. BARNHAM [b], P. BOSTOCK [c], M.L. FACCINI-TURLUER [d], H. GRÄSSLER [e], J. GUY [f], P.O. HULTH [g], K. HULTQVIST [g], U. IDSCHOK [h], H. KLEIN [a], H. KREUTZMANN [h], J. KRSTIC [c], M.M. MOBAYYEN [b], D.R.O. MORRISON [a], B. NELLEN [h], M. TALEBZADEH [b,1], W. VENUS [f], D. VIGNAUD [d], H. WACHSMUTH [a], W. WITTEK [i] and B. WÜNSCH [h]

[a] *CERN, European Organization for Nuclear Research, Geneva, Switzerland*
[b] *Imperial College of Science and Technology, London, UK*
[c] *Department of Nuclear Physics, University of Oxford, Oxford, UK*
[d] *Centre d'Etudes Nucléaires, Saclay, France*
[e] *III Physikalisches Institut der Technischen Hochschule, Aachen, West Germany*
[f] *Rutherford Appleton Laboratory, Chilton, Didcot, UK*
[g] *Institute of Physics, University of Stockholm, Stockholm, Sweden*
[h] *Physikalisches Institut der Universität Bonn, Bonn, West Germany*
[i] *Max-Planck-Institut für Physik und Astrophysik, Munich, West Germany*

Received 9 July 1985

New limits on lepton mixing parameters are derived from a search for decays of heavy neutrinos in a proton beam dump experiment. The limits $|U_{\mu i}|^2$, $|U_{ei}|^2 < 10^{-6}$–10^{-7} are obtained for neutrino mass eigenstates ν_i of mass between 0.5 and 1.75 GeV, which can be produced through mixing in charmed D meson decays. This is the first such limit on $|U_{\mu i}|^2$ for neutrino masses greater than 0.5 GeV. For the mass eigenstate ν_3 in particular, we obtain the limits $|U_{\mu 3}|^2 < 10^{-7}$–10^{-8}, $|U_{e3}|^2 < 10^{-9}$–10^{-10} for the mass range 150–190 MeV, assuming the ν_3 to be produced directly in charmed F meson decays

- Dilepton search
  - No candidate events within selection cuts
  - Known detector & film scanning efficiencies



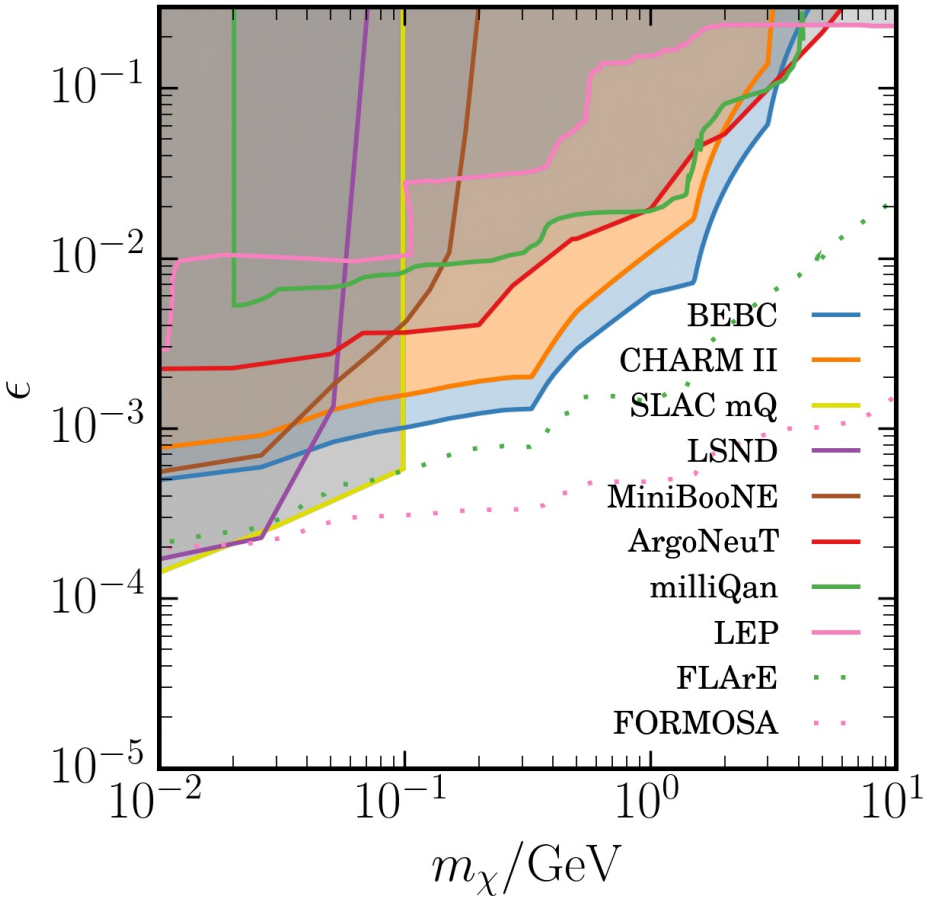
[2208.00416]
w/ Ryan Barouki
+ Subir Sarkar

Other FIPs

e.g. Millicharged particles

$Q = \epsilon e$

[2011.08153]



Conclusions

- Leading bounds on HNLs (+ other FIPs)
- Need new experiments (NA65! FASER2!) to thoroughly probe open $U_{\tau N} - m_N$ space.