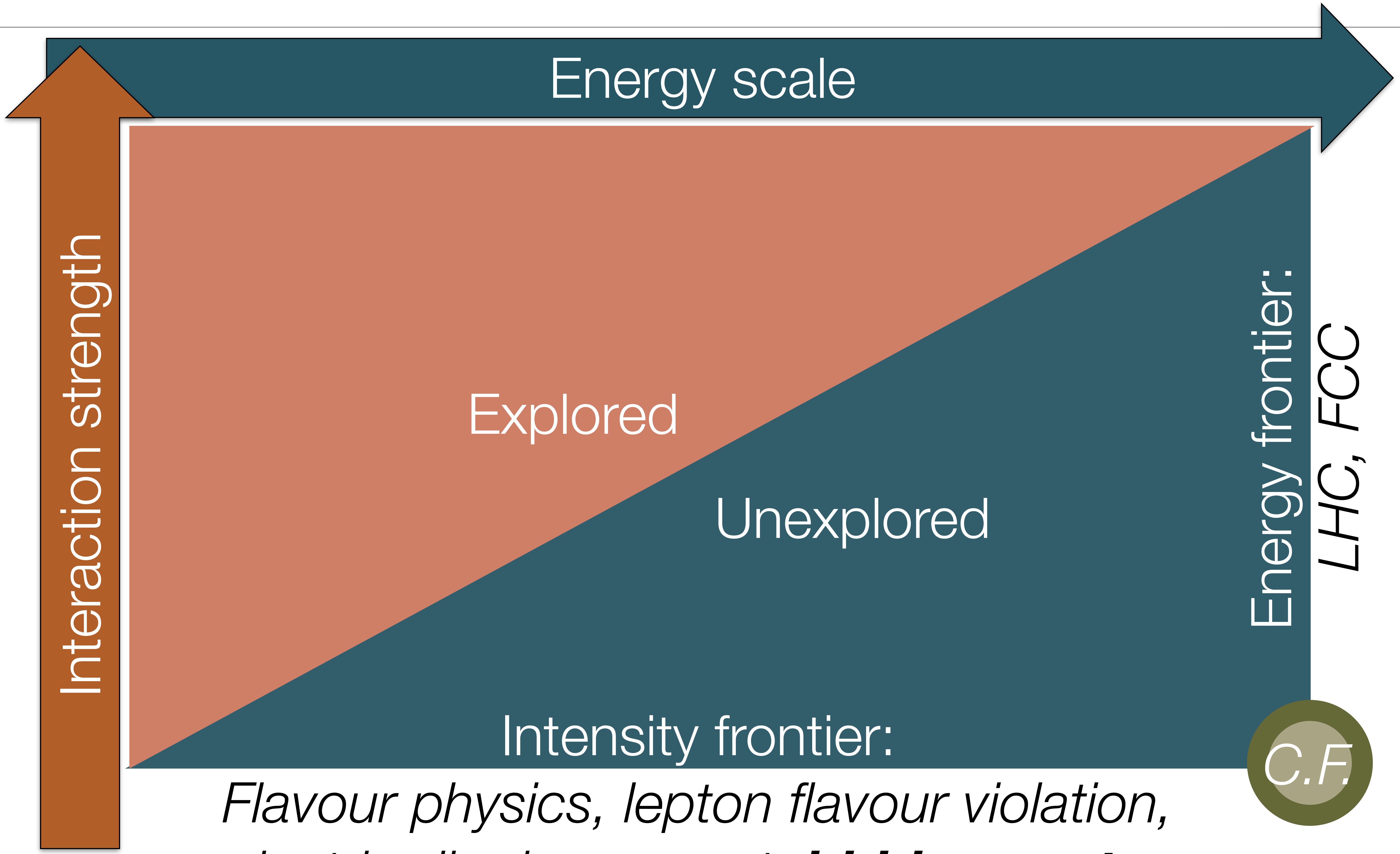
HNL in LLP searches at LHC

WG summary

ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

Introduction / 1



Flavour physics, lepton flavour violation, electric dipole moment, ***hidden sector***

Landscape today / 1

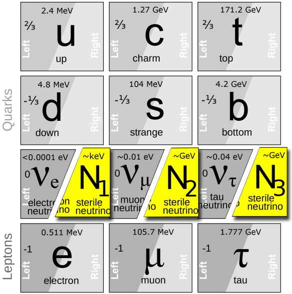
- The Intensity frontier is a **broad** and **diverse**, yet **connected**, set of science opportunities: heavy quarks, charged leptons, hidden sectors, neutrinos, nucleons and atoms, proton decay, etc...
- In this talk, I will concentrate on **dark sectors** and **lepton flavour violation** in τ.
- **Landscape**: LHC results in brief:
    - Direct searches for **NP** by **ATLAS** and **CMS** have not been successful so far
        - Parameter space for popular **BSM** models is **decreasing rapidly**, but only < 5% of the complete HL-LHC data set has been delivered so far
        - NP discovery **still may happen**!
    - **LHCb** reported intriguing hints for the violation of lepton flavour universality
        - In $b \to c\mu\nu$ / $b \to c\tau\nu$, and in $b \to s e^+ e^-$ / $b \to s\mu^+\mu^-$ decays
        - **Clear evidence of BSM** physics if substantiated with further studies (possibly by **BELLE II**)

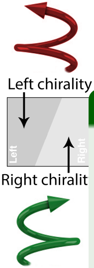
What happened

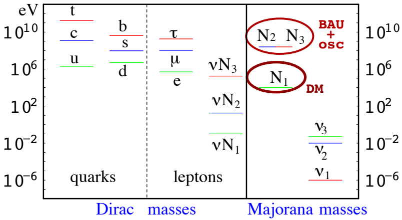
- 0) Monday 13:30: Plenary introductory by **Oliver**
- 1) Monday 16:00: Plenary introductory talks from Kyrylo **Bondarenko** and Martina **Vit**
- 2) Tuesday morning: Zhen **Liu**, Jan **Hajer**, Philippe **Mermod**, Haifa **Sfar**, and Sonia **Bouchiba**
- Thanks to all the speakers! And to all the people that participated!

Why heavy neutral leptons

Heavy neutral lepton = HNL = sterile neutrino = heavy Majorana neutrino







HNL can explain . . .

- . . . **neutrino oscillations**

  Bilenky & Pontecorvo'76; Minkowski'77; Yanagida'79; Gell-Mann et al.'79; Mohapatra & Senjanovic'80; Schechter & Valle'80

- . . . **Baryon asymmetry**

  Fukugita & Yanagida'86; Akhmedov, Smirnov & Rubakov'98; Pilaftsis & Underwood'04-05; Shaposhnikov+'05–

- . . . **Dark matter**

  Dodelson & Widrow'93; Shi & Fuller'99; Dolgov & Hansen'00; Abazajian+; Asaka, Shaposhnikov, Laine'06 –

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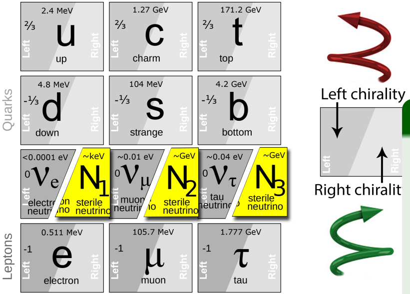

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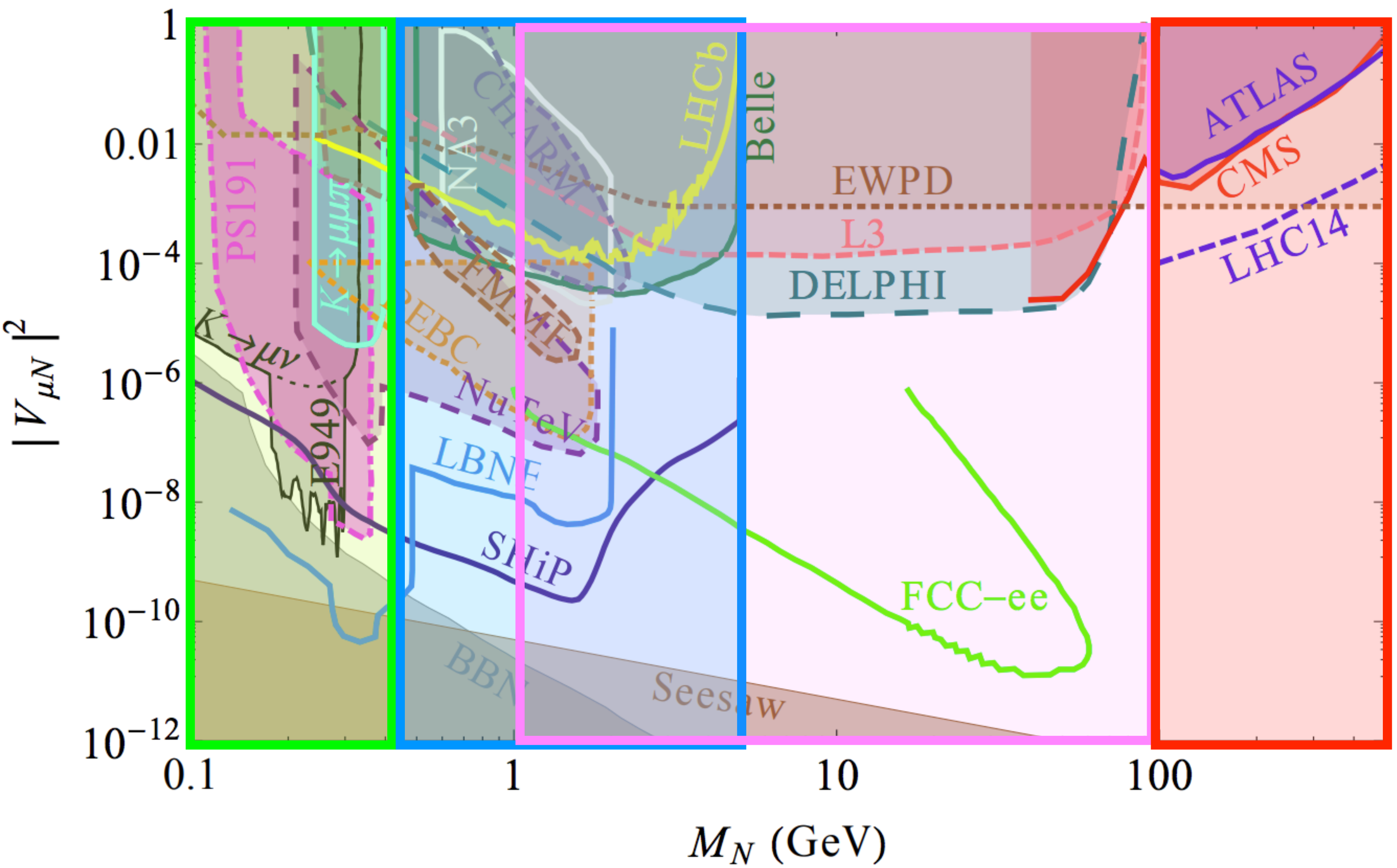
HNL can explain all of it

- **Neutrino Minimal Standard Model (νMSM)**

  Asaka & Shaposhnikov'05 + . . . hundreds of subsequent works

- Masses of HNL are of the order of masses of other leptons
- **Reviews: Boyarsky, Ruchayskiy, Shaposhnikov Ann. Rev. Nucl. Part. Sci. (2009), [0901.0011]**

Direct searches: state and projections



- $m_N > m_Z$
- LHC can exceed the limits from electroweak precision data

- $m_N < m_Z$
- Results from LEP ($Z \to \nu N$)
- Currently explored at the LHC (ATLAS, CMS)

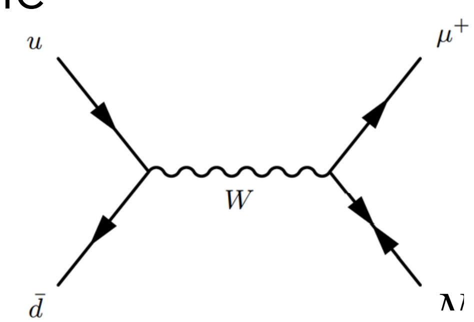
- $m_N < m_K$
- Using K decays, such as $K^{\pm} \to \ell N$, $K^{\pm} \to \mu\mu\pi$
- E.g. NA62

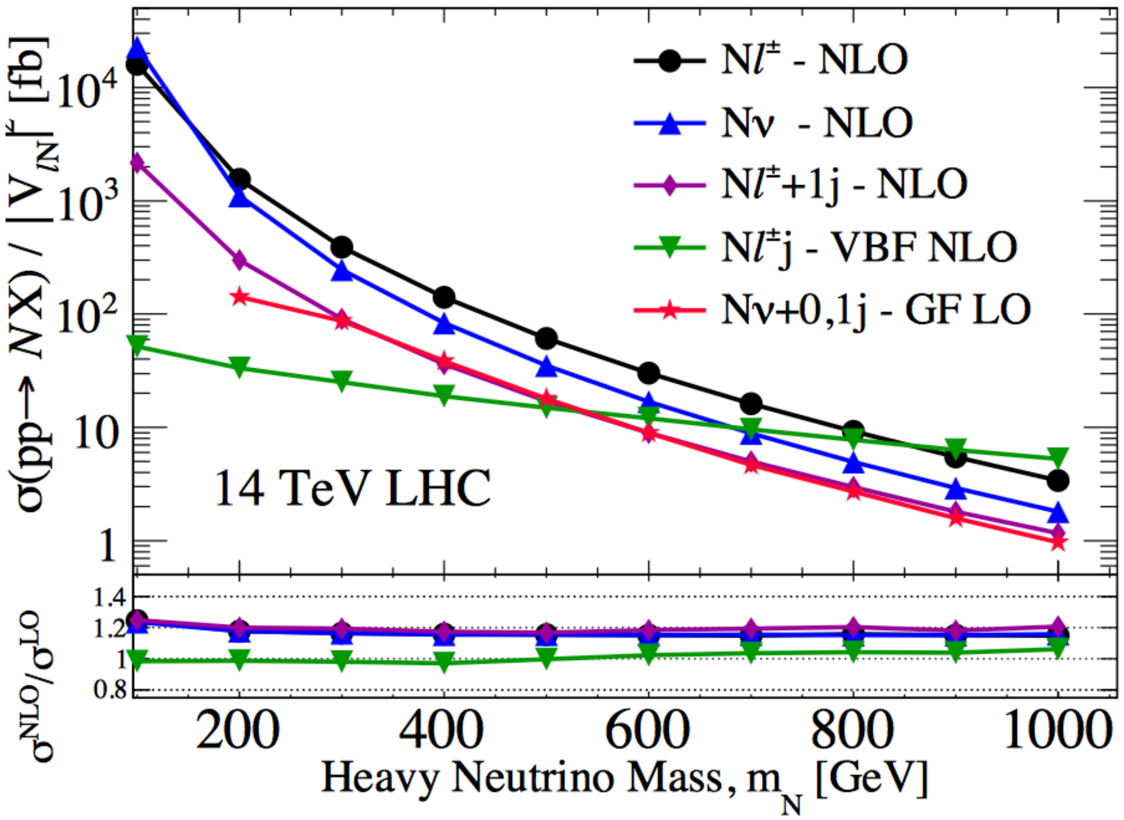
- $m_N < m_{D,B}$
- Explored at colliders (e.g. Belle, LHC*b*) or beam-dump experiments (e.g. SHiP)

arXiv:1502.06541 [hep-ph]

HNL production at LHC

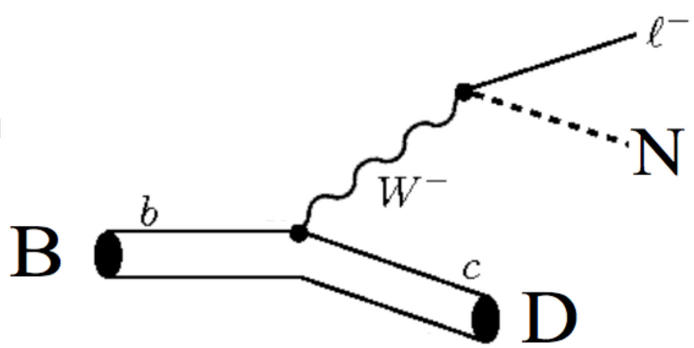
- $W^{\pm(*)}$ -> l+N (or Z/H -> νN)
  - Hight momentum lepton -> easy to trigger
  - Relatively large cross section
  - for high N masses VBF channel (Wγ fusion) becomes important
  - Final states with multiple charged-leptons ($Nl^{\pm}$) are experimentally more accessible
    - charged DY current
    - VBF (Wγ fusion)

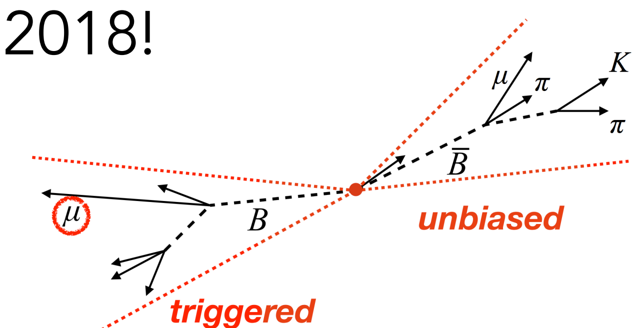


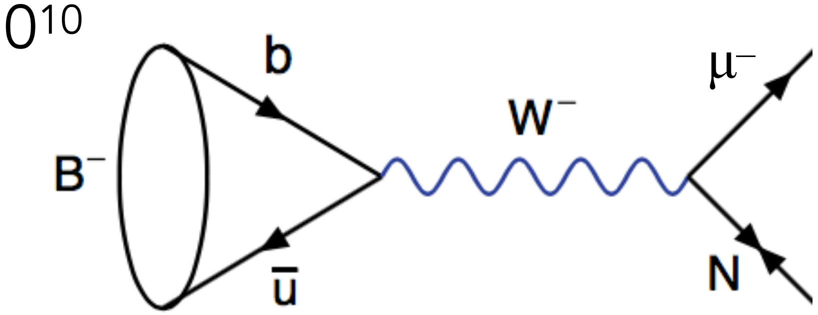


arXiv:1602.06957

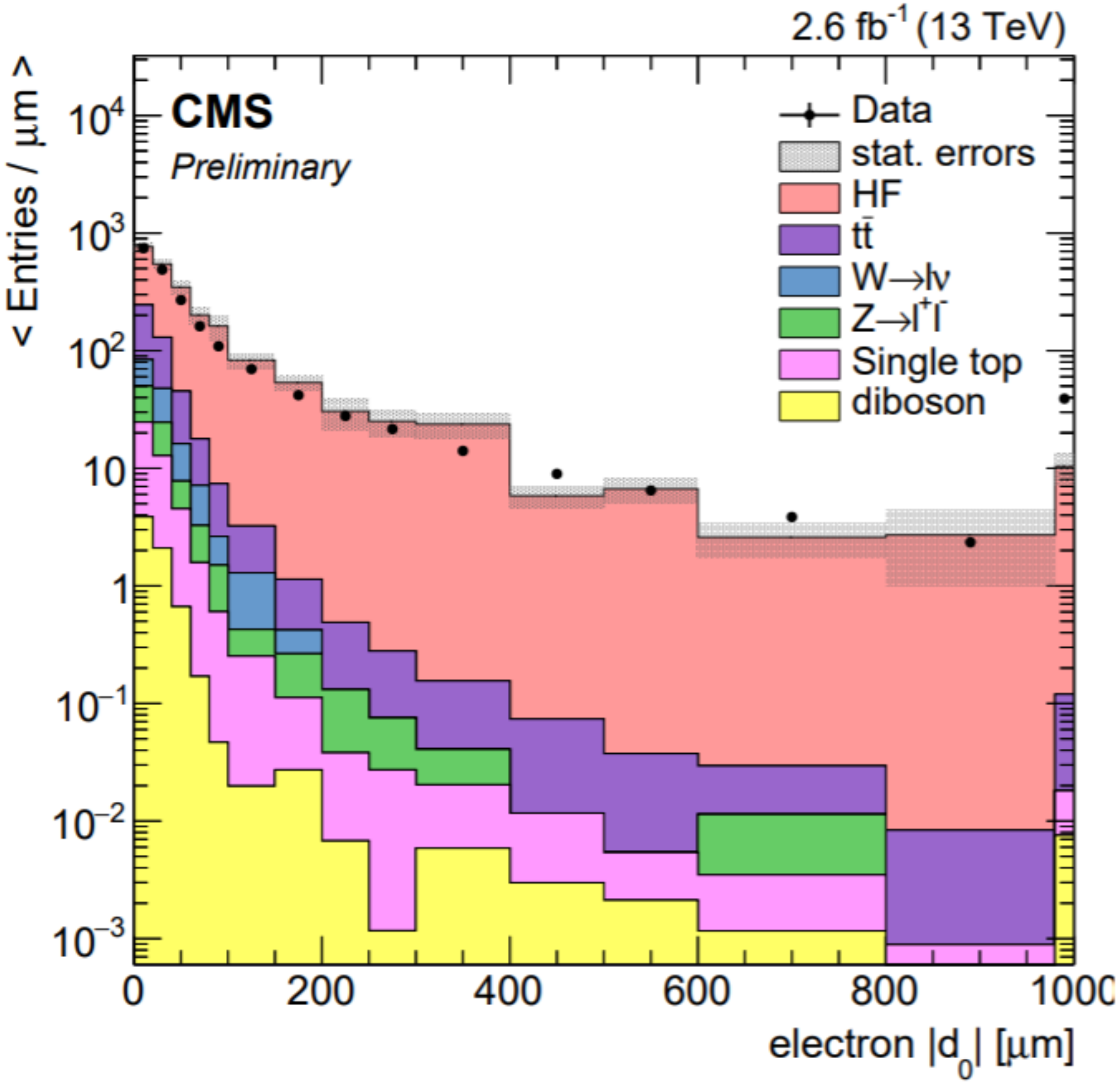
- B-hadron decays
  - **large cross section**, but large background and low-momentum ⇒ hard to trigger
  - feasible at **LHC*b***, tricky at ATLAS/CMS
    - but the **CMS "data parking"** allowed us to record ~10^{10} unbiased *B* in 2018!

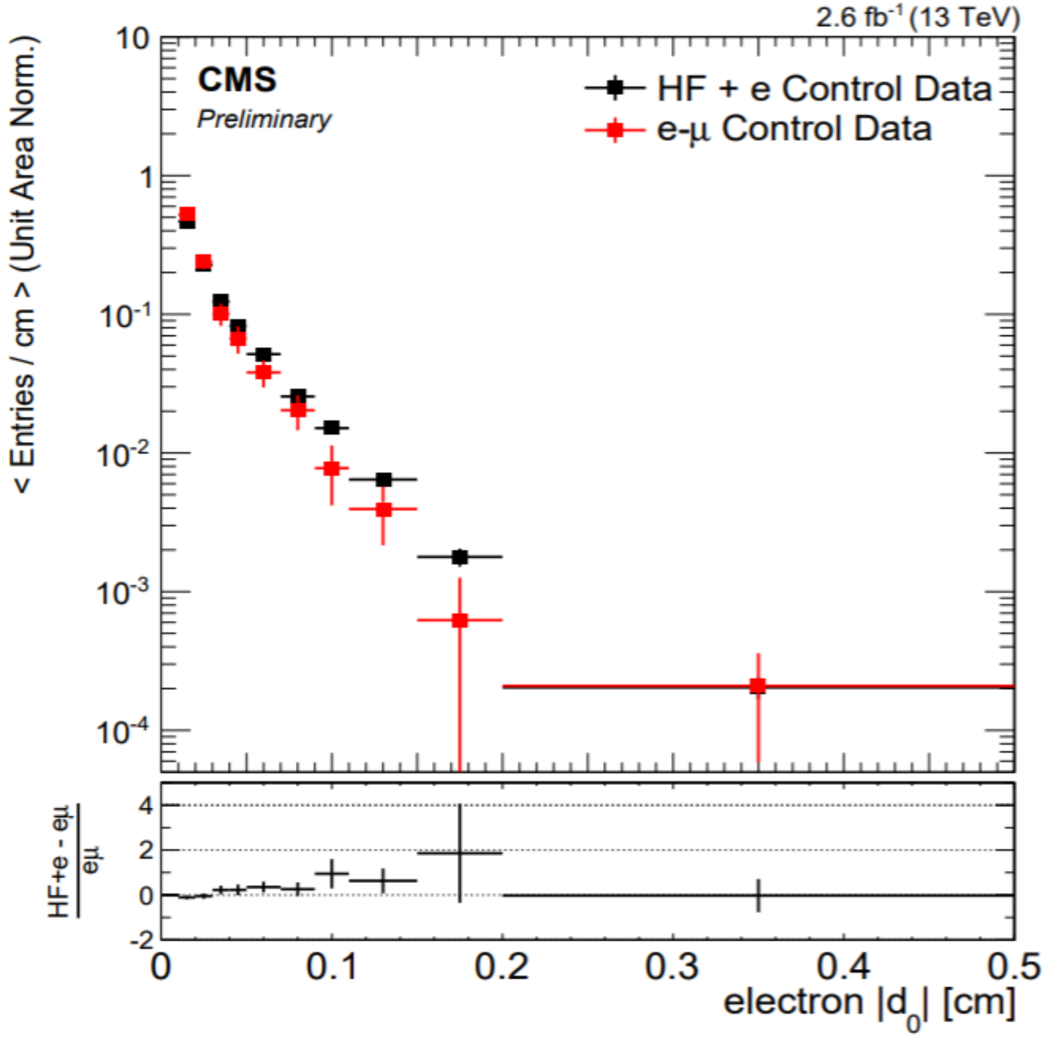






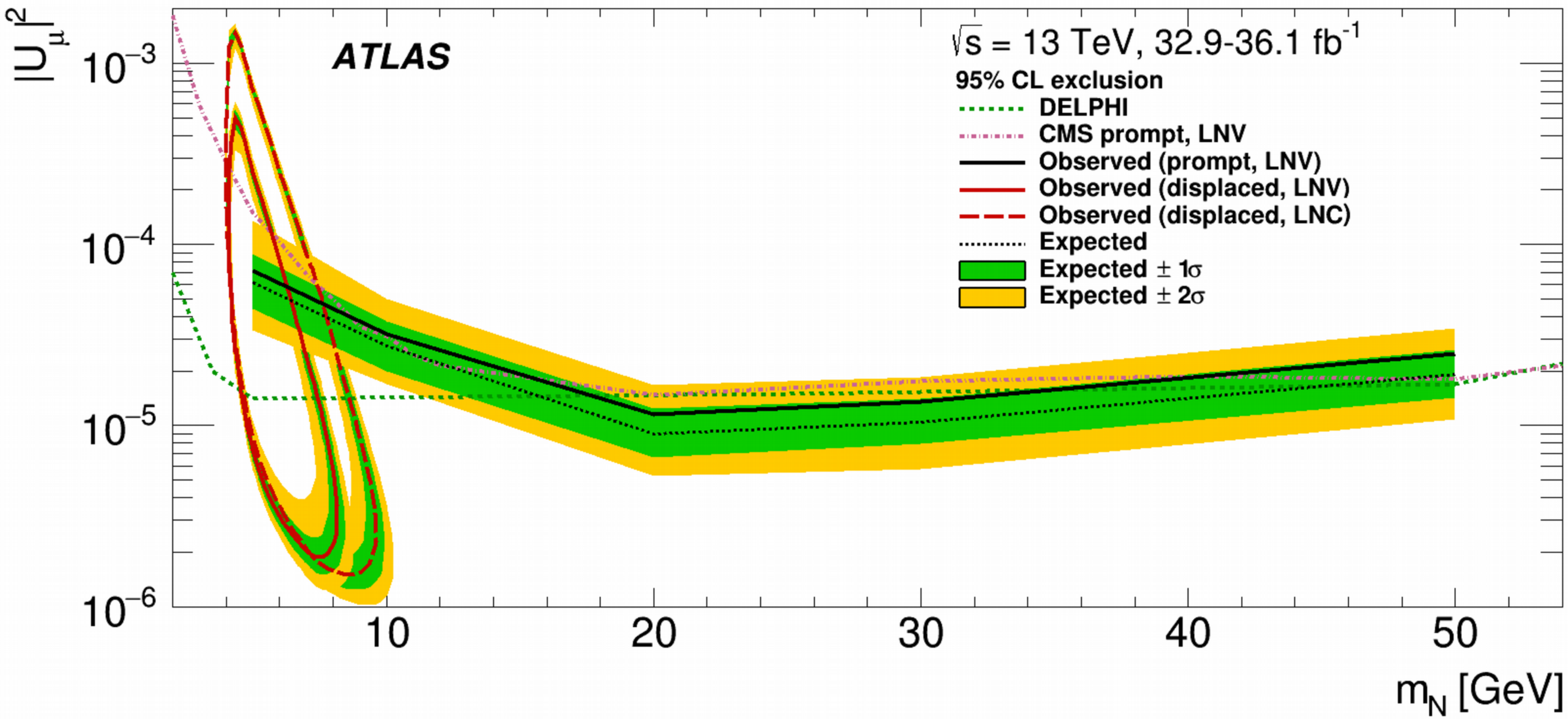
Valuable knowledge from a SUSY search





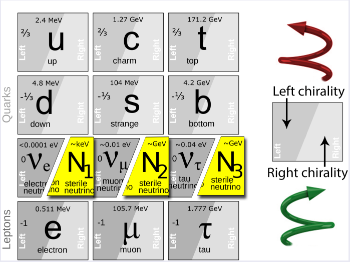
Pioneering signature : lepton + DV (low pT) for the first time at the LHC

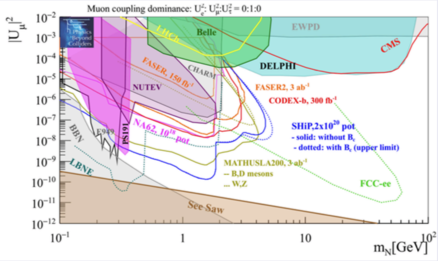
arXiv:1905.09787



Probe coupling 1 order of magnitude below Delphi for $5 < m_N < 10$ GeV

Conclusions





- HNLs naturally come as mechanism of neutrino oscillations
- Turns out that the same HNLs can resolve major BSM problems
- Searches at LHC and Intensity Frontier experiments (SHiP, FASER, . . .) are complimentary to each other
- νMSM shares all the success of the SM while at the same time is a successful cosmological model

. . . and small parameters become new slightly broken symmetries **Boyarsky [0901.0011]**

What will happen?

- Need some sort of platform to work together different from mailing list
- Shared knowledge will save lot of time to both experimentalists and theorists
- Information of background is a good example
- Need of shared benchmarks between experiments

Conclusions

- The days of "guaranteed" discoveries or of no-lose theorems in particle physics are over, at least for the time being ....
- .... but the big questions of our field remain wild open (hierarchy problem, flavour, neutrinos, DM, BAU, ...)
- This simply implies that, more than for the past 30 years, future HEP's progress is to be driven by experimental exploration, possibly renouncing/reviewing deeply rooted theoretical bias

Michelangelo Mangano

Thanks

Federico Leo Redi