Heavy Neutral Leptons and Displaced Vertices at the LHC

Based on:

Asmaa Abada, NB, Marta Losada and Xabier Marcano
arXiv:1807.10024

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UAN
UNIVERSIDAD
ANTONIO NARIÑO

3rd COMHEP
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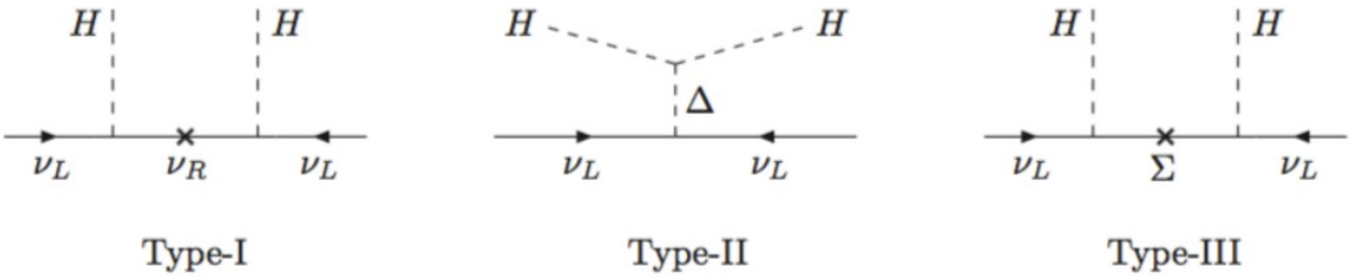
Why Heavy Neutral Leptons?

- Heavy Neutral Lepton = Right-handed Neutrino = Sterile Neutrino
- naturally present in many well-motivated BSM scenarios
- can play a role in open problems of the SM:
  - Neutrino masses
  - Baryogenesis
  - Dark Matter
  - ...

Talks by
F. Queiroz
C. Yaguna
D. Moreno
E. desPeinado
...

Seesaw models...

Heavy Neutral Leptons are present in seesaw models



Low scale seesaw models: νSM, inverse/linear seesaw…
interesting variants with lower masses and larger couplings

How heavy are these new HNL?

Talks by
C. Yaguna
D. Restrepo
J. Gutierrez

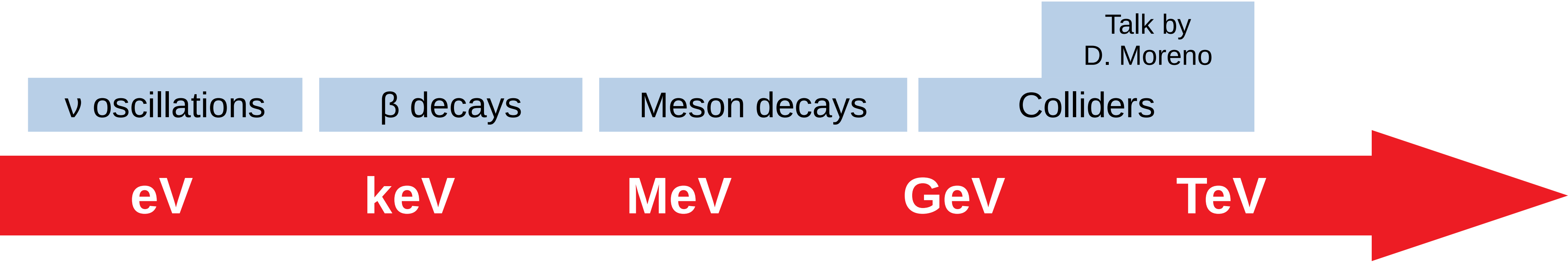
HNL mass scale

HNL mass scale

HNL mass scale

HNL mass scale

HNL mass scale



HNL mass scale

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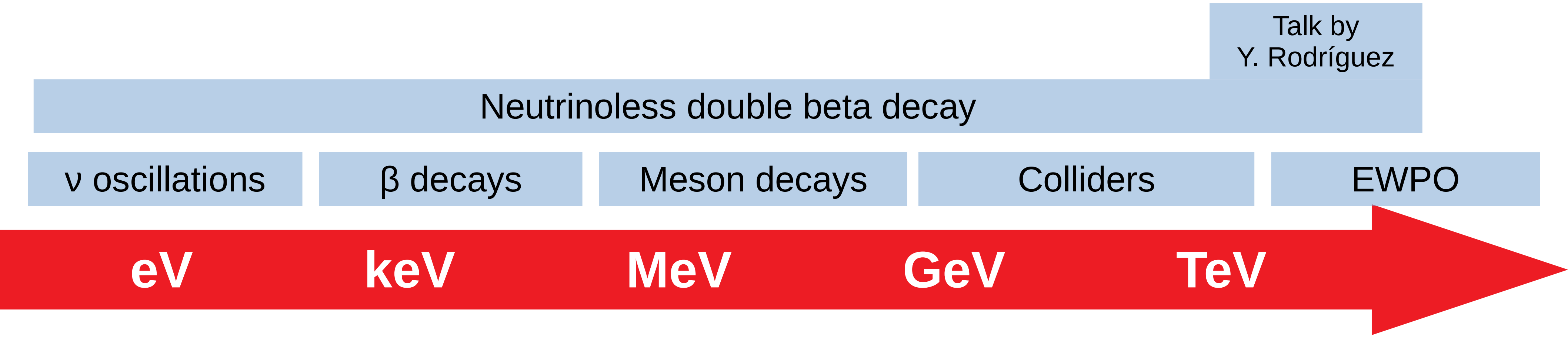

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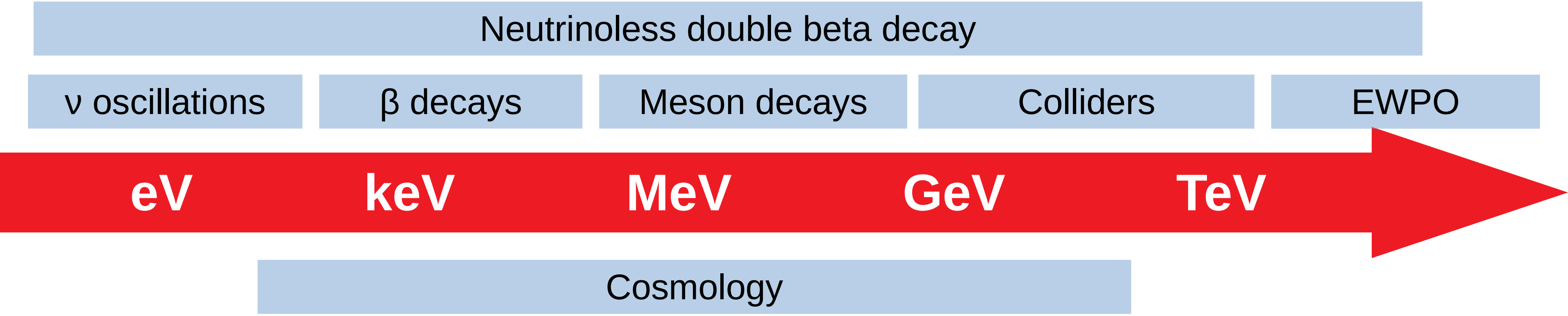

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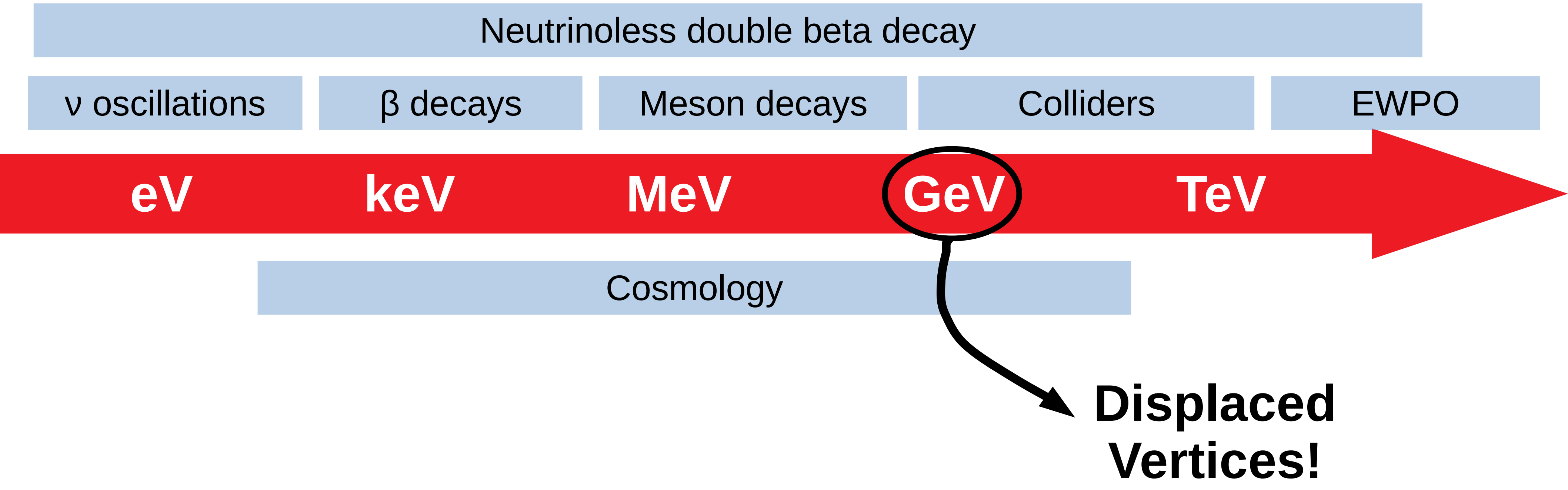

Talk by
J. Helo

Heavy Neutral Leptons: our approach

- HNL in many models and frameworks:
  Minimal extensions of the SM, seesaw models, SUSY, GUT, extra-dim...

- Bottom-up approach → SM + N

- No seesaw assumptions:
  m_N: HNL mass as a free parameter
  V_{lN}: Mixings as free parameters

Effective 3+1 neutrino model

- **1** new mass parameter $\boldsymbol{m_N}$

$$m_\nu = (m_{\nu 1}, m_{\nu 2}, m_{\nu 3}, \boldsymbol{m_N})$$

- **3** new mixing parameters $\boldsymbol{V_{lN}}$

$$U_\nu^{3+1} = \left(\begin{array}{ccc|c} & & & V_{eN} \\ & \tilde{U}_{\rm PMNS} & & V_{\mu N} \\ & & & V_{\tau N} \\ \hline V_{Ne} & V_{N\mu} & V_{N\tau} & V_{NN} \end{array}\right)$$

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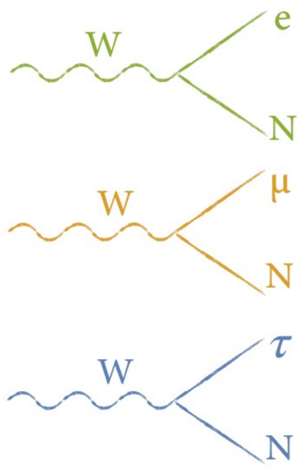
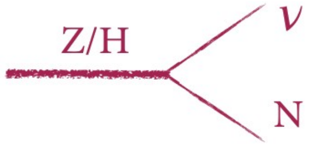
Charged currents $\propto \left|V_{\ell N}\right|^2$:

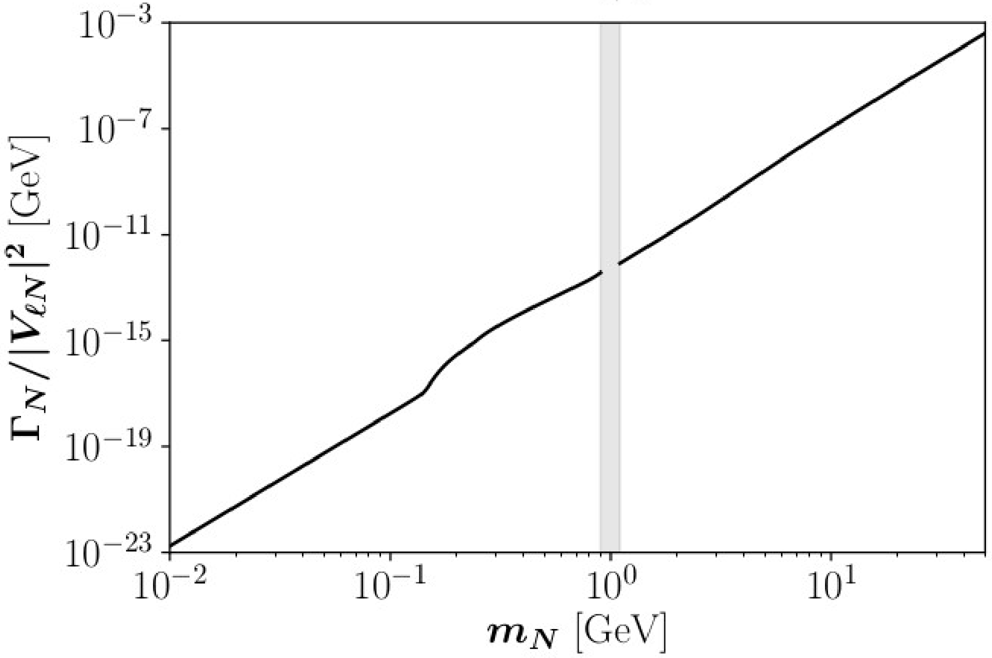


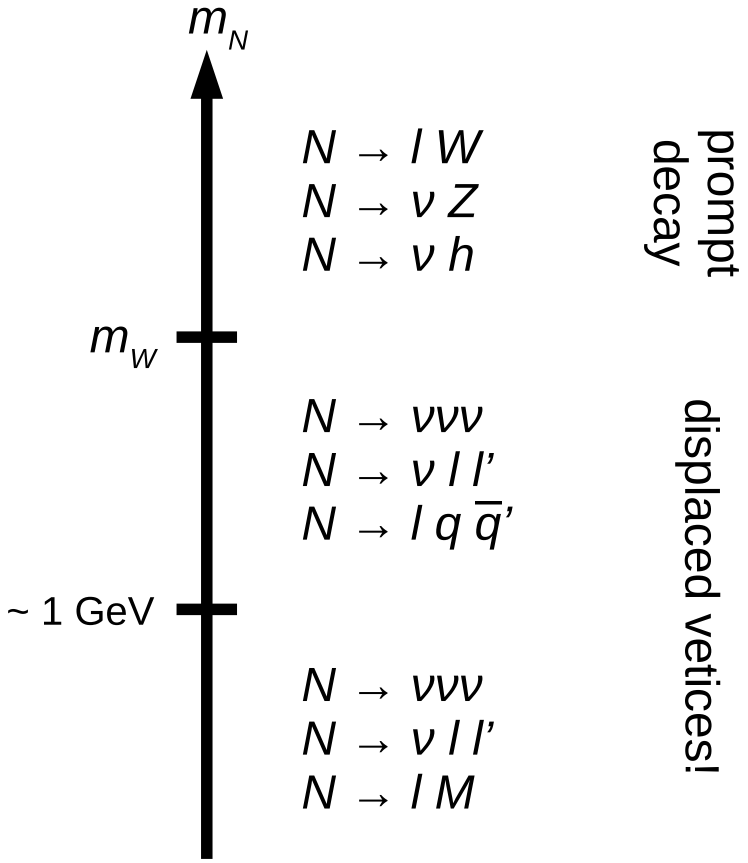
Neutral currents $\propto \sum_\ell \left|V_{\ell N}\right|^2$



Decays of the Heavy Neutral Leptons

$$\Gamma_N \propto G_F^2\, m_N^5 \sum_{\ell=e,\mu,\tau} \left|V_{\ell N}\right|^2$$





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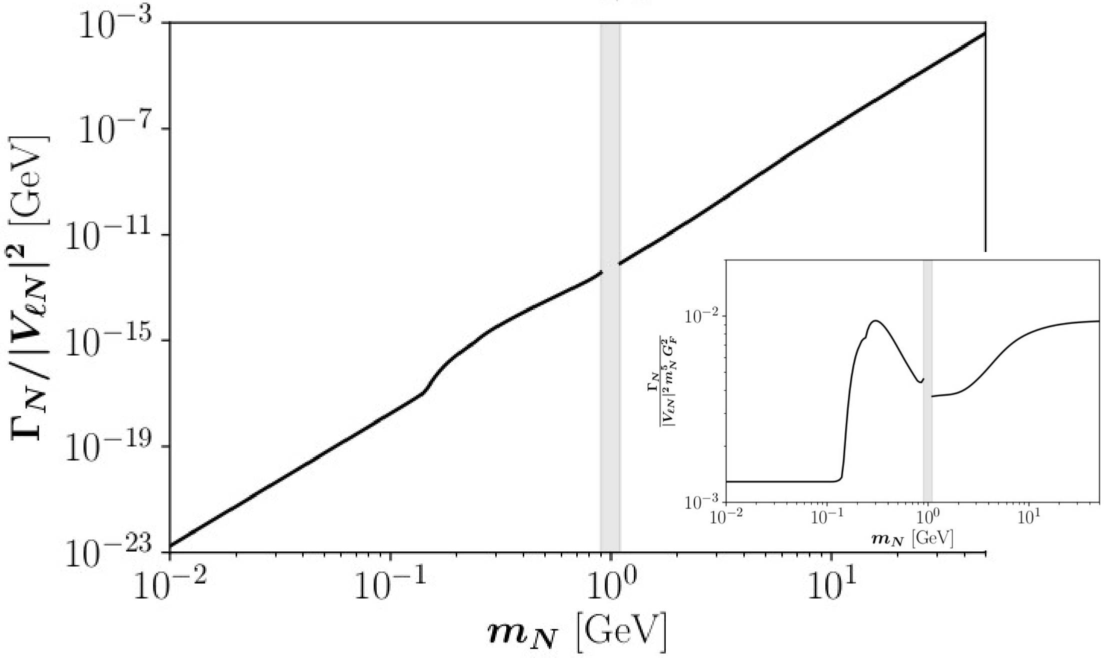

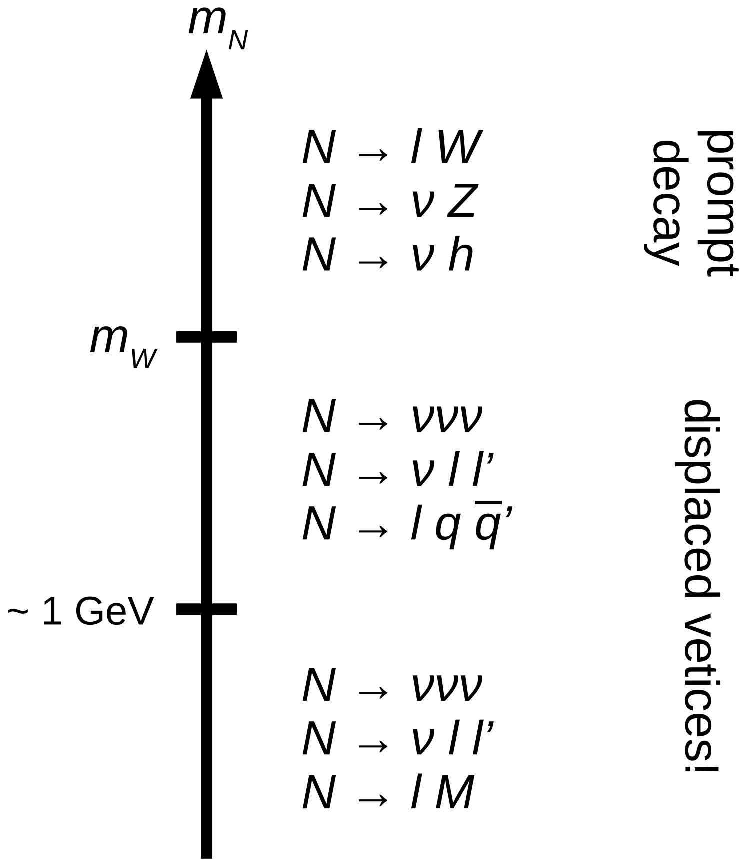

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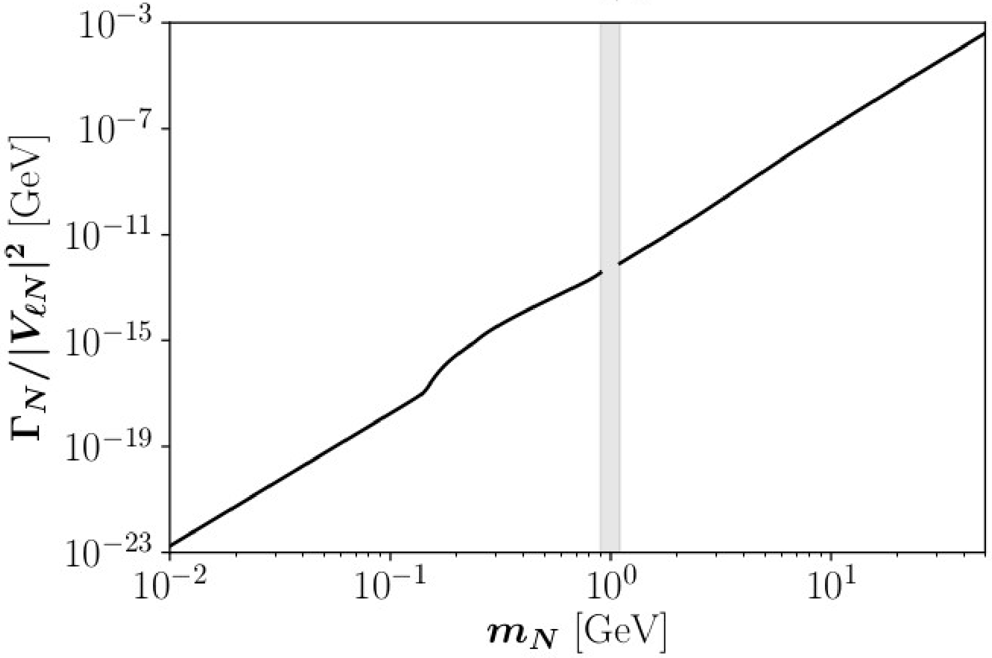
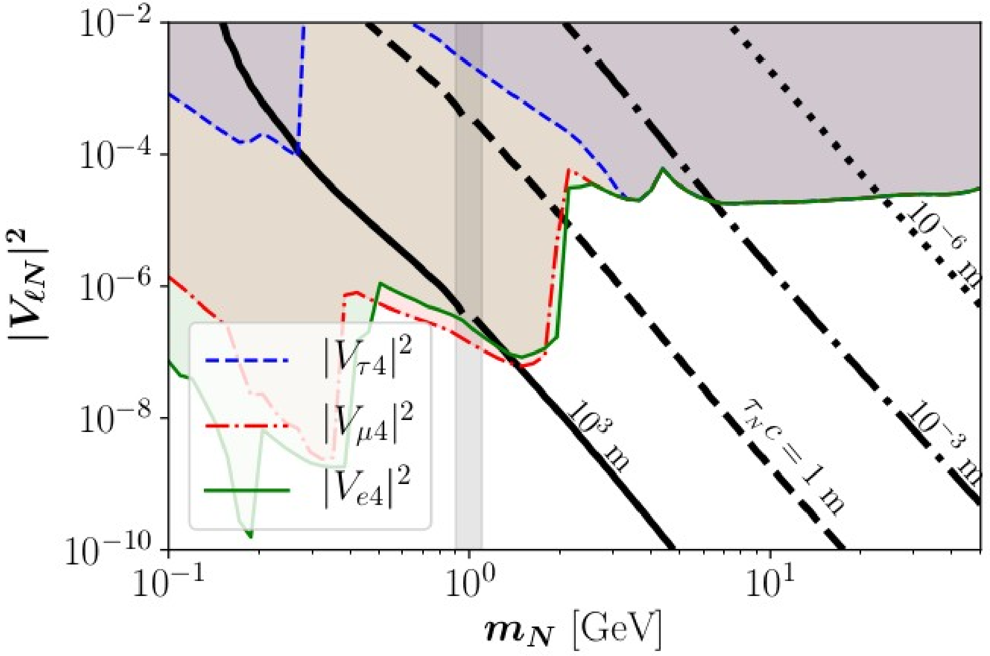
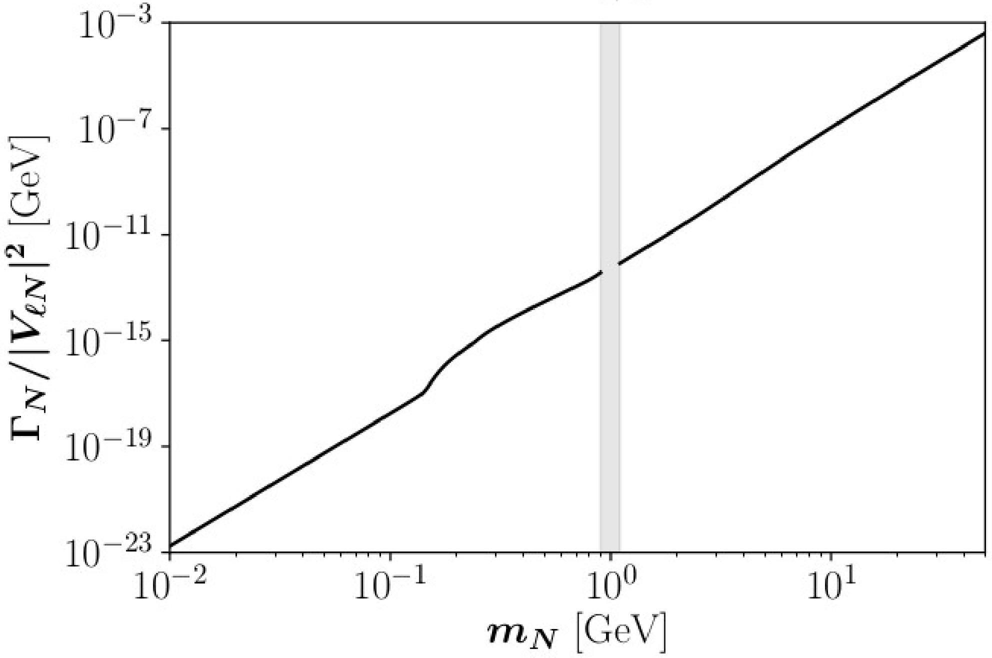
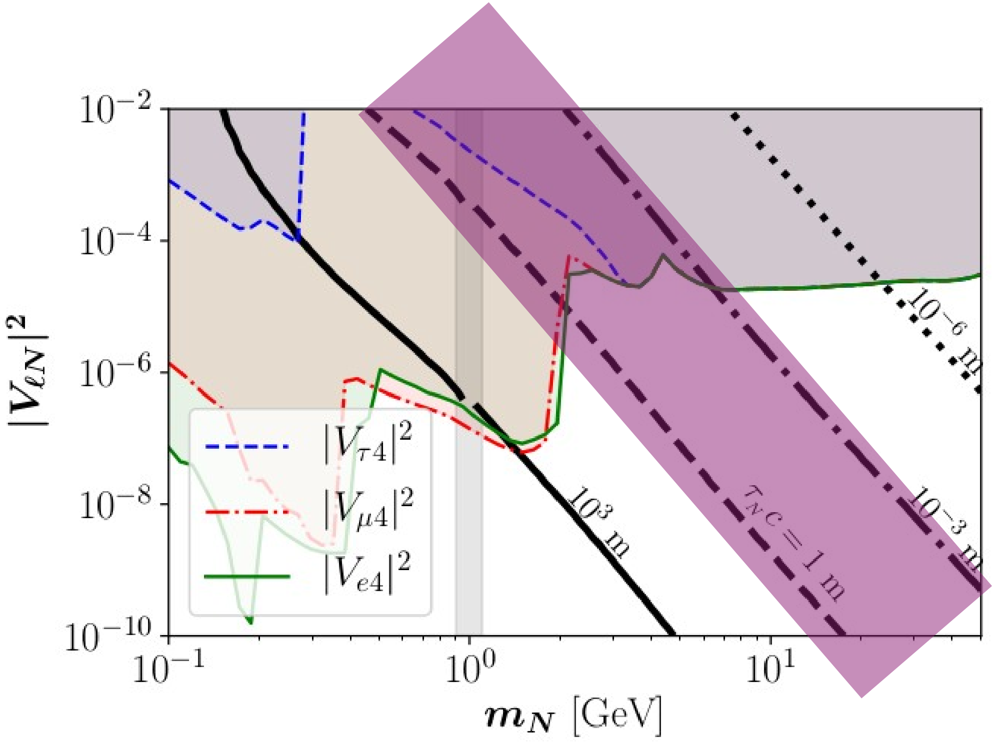




Decays of the Heavy Neutral Leptons

$$\Gamma_N \propto G_F^2\, m_N^5 \sum_{\ell=e,\mu,\tau} |V_{\ell N}|^2$$

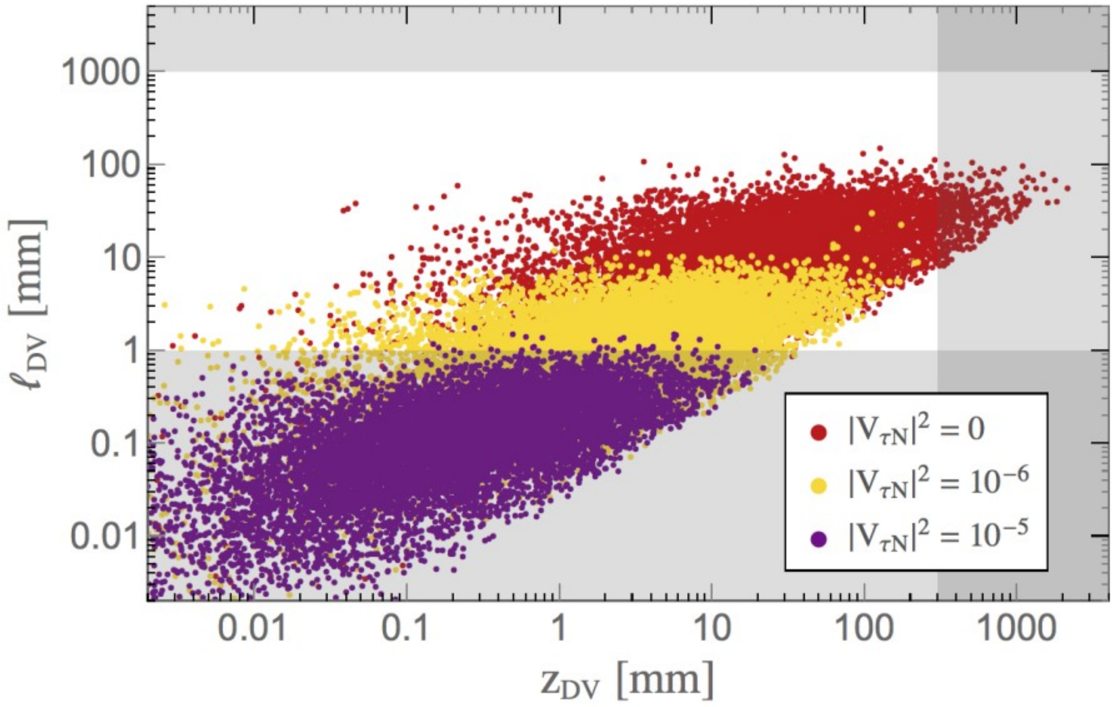




Displaced vertices @ LHC

Flavor dependence

pp* → *e*± *N



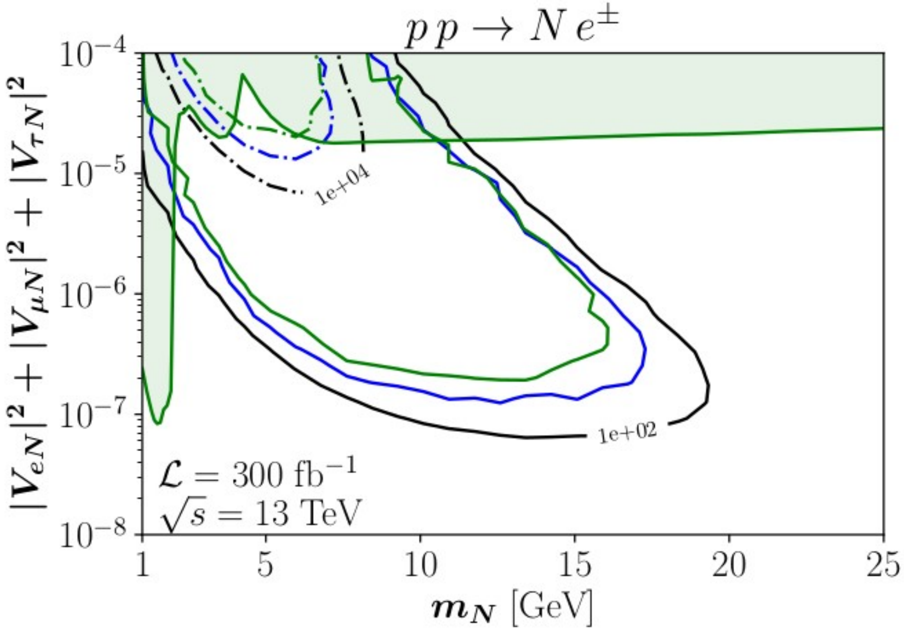
Displaced vertex:
1 mm < l_{DV} < 1m
z_{DV} < 300 mm

m_N = 15 GeV
$|V_{eN}|^2 = 10^{-7}$, $|V_{\mu N}|^2 = 0$

$p_T^e > 25$ GeV, $|\eta^e| < 2.5$

Flavor dependent production

Flavor dependent



$|V_{eN}|^2:|V_{\mu N}|^2:|V_{\tau N}|^2 = 1:0:0$ black

$|V_{eN}|^2:|V_{\mu N}|^2:|V_{\tau N}|^2 = 1:1:0$ blue

$|V_{eN}|^2:|V_{\mu N}|^2:|V_{\tau N}|^2 = 1:1:1$ green

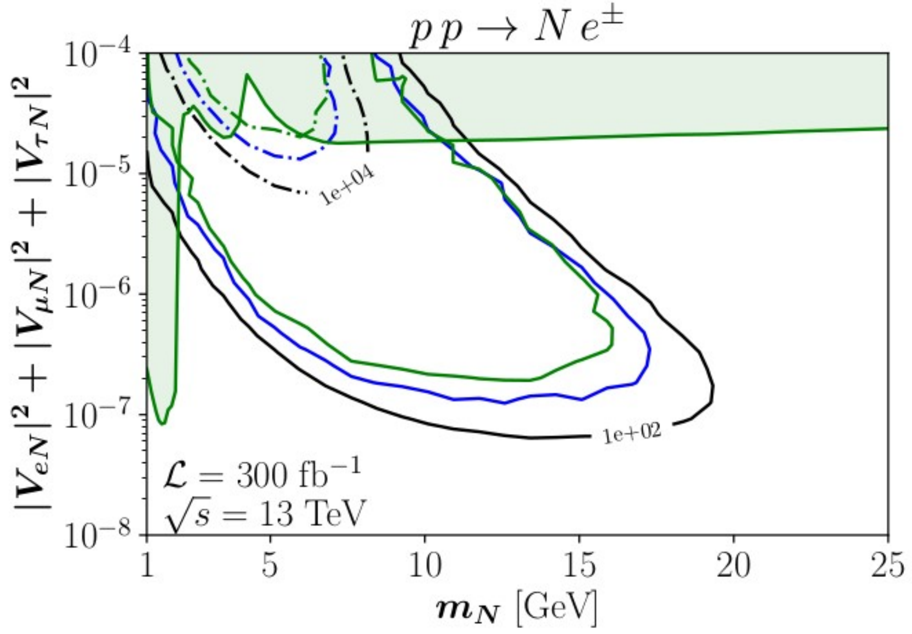
$p_T^e > 25$ GeV, $|\eta^e| < 2.5$

1 mm < l_{DV} < 1m, z_{DV} < 300 mm

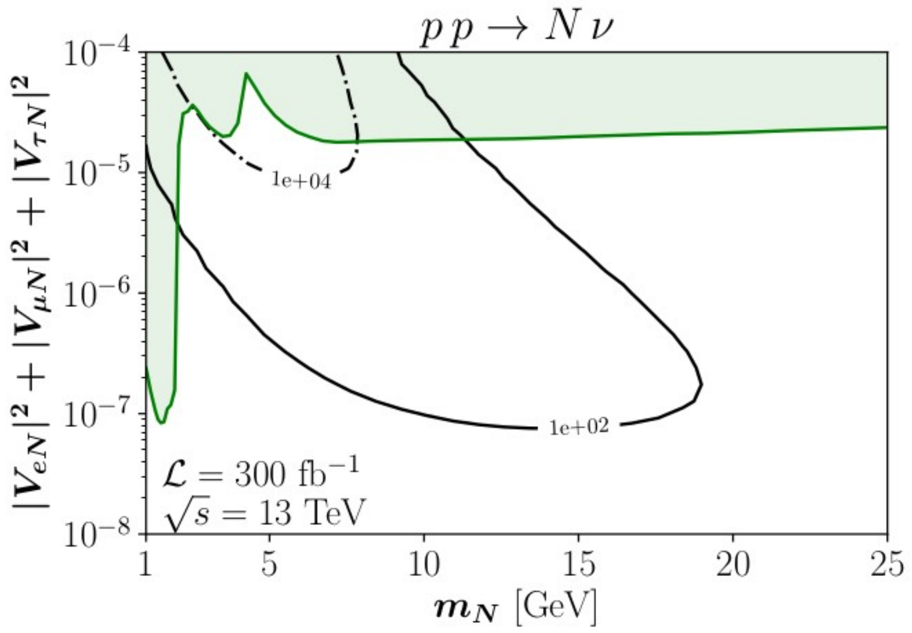
Nicolás

Flavor dependent & independent productions

Flavor dependent



Flavor independent



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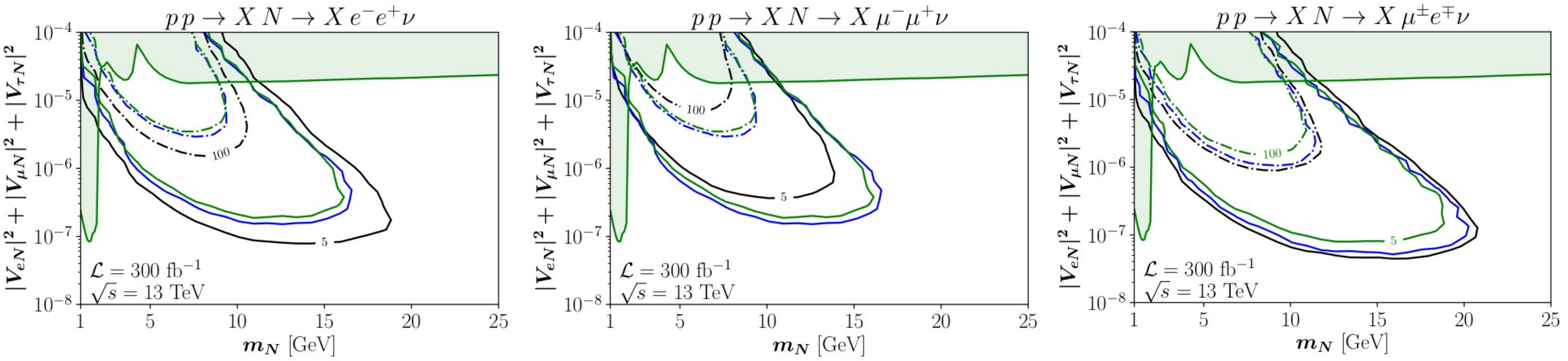
Nicolás

Displaced vertices from inclusive production



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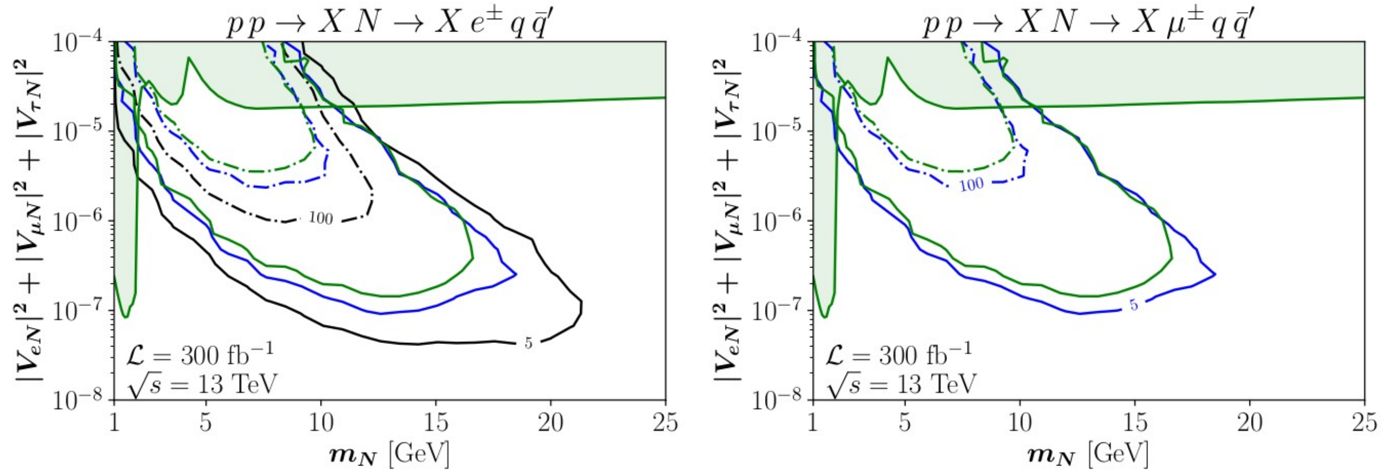
1 mm < l_{DV} < 1m, z_{DV} < 300 mm
$|\eta| < 2.5$
$p_T^e > 10$ GeV, $p_T^\mu > 5$ GeV, $p_T^j > 10$ GeV
$m_{ll'}$, $m_{ljj'} < m_N$
$\Delta R_{ll'}$, $\Delta R_{jj'} < 1$

Displaced vertices from inclusive production



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Conclusions & Outlook

- HNL naturally present in many well-motivated BSM models
- They could be at the origin of neutrino masses,
  baryon asymmetry of the universe, dark matter…
- If they are long-lived → Displaced vertices
- Different channels, all complementary
- DV @ LHC could probe new ares of the parameter space
  $m_N \sim O(10)$ GeV and $|V_{lN}|^2 > O(10^{-8})$
- LHC-HL and future colliders will go even further!

Muchas gracias, ve!

Strong-DM 2019, Searches, Theories, Results, Opportunities, and New Ideas for sub-GeV Dark Matter

New avenues are called for to solve the mystery of what is the dark matter in the Universe. The WIMP paradigm remains the best tested scenario of dark matter, but searches for new physics at the electroweak scale have come up empty-handed to-date. By 2019 the LHC will have comprehensively probed the TeV-scale, and ton-scale direct detection experiments will improve the to WIMP-nucleus scattering by an order of magnitude, probing deeply into the Higgs- mediated regime. It is essential for the field to diversify and be prepared in case of further null results.

Dark matter in the keV-GeV mass range is an exciting theoretical possibility, and is one that has become the focus of activity only in the recent past. A number of proposals have been put forward for new methods to detect light dark matter (neutrino beams and underground accelerators, electron scattering, semi- and superconducting targets, Bremsstrahlung emission, defects in crystals, among many others), and new theoretical scenarios have been entertained for the dynamics in the early Universe and their non-gravitational interactions in astrophysical environments today (Forbidden DM, SIMP DM, Impeded DM, etc.).

The workshop shall act as a forum for theorists and experimentalists to discuss searches, theories, results, opportunities, and, in general, new ideas for sub-GeV Dark Matter. It will hence be a meeting that focuses on models and regions in parameter space that are overlooked by the standard WIMP studies, and that may open a new window into the dark sector.

At a glance

Type:	Workshop
When:	Aug 05, 2019 to Aug 16, 2019
Where:	ESI, Boltzmann Lecture Hall
Organizers:	Brian Batell (U of Pittsburgh), Nicolas Bernál (U Antonio Narino),Xiaoyong Chu (HEPHY Vienna), Alejandro Ibarra (TU Munich), Hye-Sung Lee (KAIST), Josef Pradler (HEPHY Vienna, chair), Tomer Volansky (Tel Aviv U & IAS Princeton)
Add event to calendar:	vCal iCal

Dimuon channel $N \to \mu^+ \mu^- \nu$

- 2 opposite-sign collimated muons with $p_T > 15$ and 20 GeV
- Pseudorapidity $\eta < 2.5$
- Small angular separation $\Delta R_{\mu\mu} < 0.5$

Background

- Low-mass Drell-Yan processes
- Single and top pair production
- Cosmic-ray muons
- muons with relatively low momentum in multi-jet events
- muons from long-lived mesons

$$\Delta R_{\mu j} > \min\left(0.4,\ 0.04 + \frac{10\,\text{GeV}}{p_T^{\mu}}\right)$$

$$I^{\text{ID}}_{\Delta R=0.4} \equiv \frac{\sum_j |p_T^j|}{p_T^{\mu}} < 0.05$$

$$\sqrt{(\Delta\eta_{\mu\mu})^2 + (\pi - \Delta\phi_{\mu\mu})^2} > 0.1$$

$$H_T < 60\ \text{GeV}$$

$$5\ \text{GeV} < m_{\mu\mu} < m_N$$

ATLAS collaboration, M. Aaboud et al., *Search for long-lived particles in final states with displaced dimuon vertices in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector*, 1808.03057.